EGF 2018

17[TH] - 21[ST] JUNE 2018 | CORK, IRELAND

Sustainable meat and milk production from grasslands

Edited by

B. Horan
D. Hennessy
M. O'Donovan
E. Kennedy
B. McCarthy
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B. O'Brien

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Proceedings of the 27th General Meeting of the European Grassland Federation
Cork, Ireland
17-21 June 2018

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Foreword

We would like to welcome all delegates of the European Grassland Federation 27th General Meeting to Cork, Ireland. The EGF last visited Ireland in 1988. The main theme of the 27th General Meeting of the European Grassland Federation is 'Sustainable Meat and Milk Production from Grassland'. The conference will focus on sustainable production from grassland incorporating the three pillars of sustainability - economic, social and environmental. It will provide an opportunity to consider new methods of increasing utilisation of grassland in ruminant diets (dairy, beef and sheep), while enhancing grassland ecosystem services. Technology is playing a bigger role in agriculture and this conference will examine the role of incorporating smart technology in grass based ruminant production systems, as well as harvesting big data reservoirs in grassland research to enhance resource management. Transferring research to practice is crucial to ensure sustainable production and therefore exploring knowledge transfer from research to farm will be a key component of EGF 2018.

The conference has six sessions focusing on: (1) Resilient plants for grass based ruminant production systems, adapting grassland systems to the dynamics of climate and resource availability; (2) Appropriate livestock for grasslands, key characteristics of animals adapted to and suitable for grasslands; (3) Environmental influences on grassland systems – consequences of climate change, mitigation strategies, and impacts on ecosystems; (4) Social and economic impacts of grass based ruminant production; (5) Big data and smart technologies in grassland; and (6) Knowledge transfer to stakeholders.

The opening session of the conference will provide an overview of the role of grassland in European ruminant production systems, as well as describing current ruminant production systems in Ireland.

All delegates will visit Teagasc, Animal and Grassland Research and Innovation Centre at Moorepark, for an overview of the many aspects of grassland research on-going at Teagasc. After the visit to Moorepark, there are five mid-conference tours visiting research farms, some of Irelands leading grass based dairy, beef and sheep farms, the Department of Agriculture, Food and the Marine Grass and Clover Evaluation programme, one of Ireland's leading assembler, importer and distributor of forage seed, and a dairy processor.

The post-conference tour will visit a number of Teagasc Research Centres, the Burren Project, and the Agri-Food Bioscience Institute in Northern Ireland, as well as enjoying the scenery of Ireland and exploring it's rich history.

The General Meeting is organised by Teagasc, The Agriculture and Food Development Authority in Ireland. The Animal and Grassland Research and Innovation Programme has a wide range of research projects including grassland and grazing management, animal breeding, nutrition, precision agriculture, animal welfare, and environmental and economic sustainability, as well as being deeply involved in dissemination and knowledge transfer.

Our thanks to the EGF Executive Committee for accepting our bid to host the 27th General Meeting; we hope that we can continue the tradition of high quality and impactful meetings which have characterised previous EGF General Meetings.

We would like to thank all authors for their papers and presentations, the numerous reviewers for their important comments and contributions which have helped to ensure the high quality of the papers presented, the members of the scientific and organising committees, the secretary of EGF, and our sponsors and supporters.

We hope that the 27th General Meeting of EGF will stimulate fruitful discussions and networking, identify common goals and develop new research collaborations. We hope that delegates enjoy their visit to Cork.

Prof. Frank O'Mara
President, European
Grassland Federation

Dr. Deirdre Hennessy
Secretary, EGF 2018

Dr. Michael O'Donovan
Chairperson, EGF 2018

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Opening session

The evolution of grassland in the European Union in terms of utilisation, productivity, food security and the importance of adoption of technical innovations in increasing sustainability of pasture-based ruminant production systems

Dillon P.G.

Teagasc, Animal & Grassland Research and Innovation Centre, Moorepark, Co. Cork, Ireland

Abstract

Over 174 million hectares in the EU-28 are used for agriculture of which 59.8% is used for arable crops, 34.2% for permanent grassland and 5.9% for permanent crops. Between 1970 and 2013, the amount of permanent grassland in the EU was reduced by 5.9 million hectares; the greatest reductions occurring in Germany, the Netherlands, France, Denmark and Belgium. The most productive grassland sites in Europe (>15 t DM ha^{-1}) are located on the Atlantic side between 52° and 57° N latitude. These include the Netherlands, Great Britain, Ireland, Belgium, north-western France and northern Germany. The more productive areas generally have longer grazing seasons, an important parameter in pasture-based ruminant production systems. A long grazing season can increase the quantity of grazed pasture in ruminant diets and reduce other feed costs. Average grazing season length in the EU-28 is currently 6.1 months and is predicted to increase to 6.8 months by 2070. Pasture-based ruminant production systems are generally viewed in a positive manner by consumers. Pasture-based ruminant production systems can contribute to global food by producing human edible protein from non-edible forages. It is estimated that globally 2.8 kg of human edible feed in ruminant systems and 3.2 kg in monogastric systems are required to produce 1 kg of boneless meat, however, these figures disguise large variations in feed conversion efficiency. Opportunities to further increase the efficiency of European pasture-based systems of livestock production include the application of more appropriate breeding and evaluation programmes for pasture species, using animal genetics best suited for pasture-based systems, using mixed pasture species and increasing farm nutrient efficiency. There is a significant opportunity to develop easy to use decision support tools for grassland farmers to increase the efficiency of pasture-based systems.

Keywords: land use, utilisable agricultural area, grazing season length, edible protein, animal genetics, decision support tools

Introduction

European pasture-based ruminant production systems face a threefold challenge: (1) to meet the increasing global demand for food; (2) to do so in an environmentally sustainable manner; and (3) to ensure that the products produced meet the highest standards of sustainability, sanitary quality and nutritional value for increasingly discerning consumers. The aim of this paper is to examine recent trends in the utilisation of agricultural land in Europe; grassland productivity, grazing season length, the impact of climate change, role of grassland in food security and the opportunities to further improve the efficiency of European grass-based systems of livestock production.

Land cover in EU27

Forest and woodland areas occupied 37% of the total area of the EU-27 in 2012, cropland 25%, grassland 21%, shrub land 7%, water areas and wet lands 5% and built up areas 4%. There was significant variation between countries in terms of type of land cover area (Table 1). Forest and woodlands were the prevailing land cover in the northern part of Europe and for member states whose typography is dominated by mountain and hilly areas. The proportion of land under forest and woodlands exceeded 60% in Finland, Sweden and Slovenia; exceeded 50% in Estonia and Latvia and exceeded 40% in Austria and Slovakia. Denmark and Hungry had greater than 45% of land cover under cropland, with most of the remaining EU countries having between 17 and 35%. The countries with the smallest proportion of land utilised for crops were Finland, Ireland and Sweden (all less than 7%). Natural and agricultural grassland dominated in Ireland (64%) and United Kingdom (43%); followed by the Netherlands (39%), Luxembourg (33%) and Belgium (32%). Most of the remaining EU countries had between 19 and 30% grassland, with the exception of Italy, Portugal, Spain, Greece, Cyprus and Malta (all countries in southern Europe) plus Sweden and Finland (extreme north) all being less than 17% grassland.

Table 1. EU27 land cover type in 2012 (% of total area) (Eurostat, 2014).[1]

	Woodland	Cropland	Grassland	Shrubland	Water areas and wetland	Artificial land	Bare land
EU-27	37.1	24.8	20.7	6.6	4.8	4.1	1.7
Finland	66.1	6.3	3.7	5.6	15.9	1.6	0.7
Sweden	62.9	4.2	5.6	8.9	14.4	1.6	2.6
Slovenia	60.0	10.8	21.4	2.1	1.1	3.2	1.4
Estonia	53.5	11.3	19.5	2.8	10.1	1.8	1.0
Latvia	52.6	12.7	24.6	1.8	5.7	1.6	1.0
Austria	47.1	17.7	24.1	2.0	2.1	4.9	2.1
Slovakia[2]	45.1	28.0	19.6	2.9	1.2	2.8	0.4
Bulgaria	37.7	32.0	20.6	6.1	1.0	1.8	0.8
Czech Republic	37.5	34.3	20.8	0.8	1.6	4.4	0.7
Portugal	37.2	17.8	16.2	17.7	1.9	5.5	3.8
Lithuania	36.3	26.3	29.6	1.1	3.6	2.4	0.6
Poland	33.7	34.5	24.3	1.1	2.4	3.3	0.8
Luxembourg[3]	33.2	20.8	33.3	1.0	0.7	10.1	0.9
Italy	32.9	32.8	16.7	6.5	2.7	7.0	1.3
Germany	32.8	32.9	22.9	1.0	2.3	7.2	0.8
Romania	30.9	35.0	27.0	1.7	2.7	2.1	0.6
France	30.7	30.9	27.2	3.6	1.6	5.2	0.7
Greece	30.2	23.1	13.5	25.5	1.9	3.5	2.2
Spain	29.6	28.1	15.7	16.6	1.0	3.5	5.3
Belgium	24.4	29.0	32.1	0.4	1.5	12.1	0.5
Hungary	22.7	46.7	20.9	2.1	3.3	3.3	1.0
Cyprus[2]	19.4	34.0	13.2	21.6	0.6	6.5	4.7
Denmark	17.7	48.7	22.1	1.2	2.6	6.9	1.0
United Kingdom	15.1	21.1	43.2	8.8	4.9	6.0	0.9
Netherlands	12.6	25.9	38.8	1.6	7.4	12.3	1.4
Ireland	11.7	5.9	63.6	5.7	8.7	3.9	0.5
Malta[4]	3.8	26.3	11.4	16.1	2.5	32.6	7.6

[1] Ranked on the share of woodland areas. Croatia: not available.

[2] Water areas and wetland: low reliability.

[3] Shrubland and bare land: low reliability.

[4] Woodland and water areas and wetland: low reliability.

Land use in EU27

Agriculture land use is the most common primary land use category in the EU27, accounting for 43.5% of total land area in 2012 (Table 2). The land area used for forestry covered 32.4%, while 5.7% was used for services, residential and recreational purposes. Industrial, transport, energy production and mining purposes claimed a further 3.4%, leaving a residual category accounting for the remaining 15%. The highest proportion of agricultural use was in Ireland (71.5%), while Denmark, United Kingdom, Hungary and Romania all had more than 60%. Agriculture played a minor role in land use in Finland and Sweden accounting for less than 10% in both countries. In Finland, Sweden, Slovenia, Estonia and Latvia, more than 50% of the area was used for forestry purposes; whereas less than 10% was used for forestry in Ireland, Cyprus and the Netherlands.

Table 2. EU27 primary land use type in 2012 (% of total area) (Eurostat, 2014).[1]

	Agricultural use	Forestry use	Services, recreational and residential use	Industry, mining and transport use	Other use or no visible use
EU-27	43.5	32.4	5.7	3.4	15.0
Ireland	71.5	8.8	5.1	5.1	9.5
Denmark	63.9	12.3	11.3	4.0	8.5
United Kingdom	63.5	10.3	9.8	3.6	12.8
Hungary	61.8	22.7	5.4	2.9	7.2
Romania	60.3	31.3	2.0	1.5	4.9
Netherlands	56.9	4.7	17.2	11.9	9.3
France	54.0	25.9	6.9	4.0	9.2
Lithuania	52.9	35.8	3.2	2.1	6.0
Germany	52.0	29.4	8.5	5.6	4.5
Belgium	51.8	20.4	15.9	6.6	5.3
Poland	51.6	30.9	5.4	2.7	9.4
Luxembourg	51.1	33.8	6.4	7.2	1.5
Czech Republic	50.2	34.4	5.8	3.8	5.8
Bulgaria	49.4	34.9	2.2	1.7	11.8
Italy	48.0	21.6	6.0	4.3	20.1
Spain	47.9	19.8	2.2	3.2	26.9
Portugal	41.4	33.1	3.2	4.2	18.1
Slovakia	41.2	42.5	4.3	2.5	9.5
Cyprus	40.2	7.5	5.1	4.3	42.9
Austria	38.0	47.7	4.9	3.5	5.9
Greece	37.2	22.9	2.5	3.1	34.3
Malta[2]	35.1	:	23.7	8.9	32.3
Latvia	31.6	51.5	3.6	2.3	11.0
Slovenia	29.7	55.2	4.7	2.8	7.6
Estonia	27.1	53.0	6.0	3.0	10.9
Sweden	8.2	57.8	5.5	1.9	26.6
Finland	8.1	63.0	7.6	2.3	19.0

[1] Ranked on the share of land used for agriculture.

[2] Forestry use: not available.

Table 3. Utilisation of agricultural area in Europe (Eurostat, 2014).

	Agricultural Area (ha)	UAA (ha)	Proportion of UAA (%)			
			Arable land	Permanent grassland/meadows	Permanent crops	Other
EU-28	213,503,110	174,358,310	59.8	34.2	5.9	0.2
Ireland	5,277,990	4,959,450	21.0	79.0	0.0	0.0
United King.	18,417,700	17,096,170	36.7	63.1	0.2	0.0
Hungary	7,048,760	4,656,520	81.6	15.1	3.0	0.3
Austria	5,815,840	2,726,890	50.0	47.5	2.4	0.1
Denmark	2,922,230	2,619,340	91.5	7.5	1.0	0.0
Czech Rep.	5,076,430	3,491,470	71.4	27.5	1.1	0.0
Romania	14,661,380	13,055,850	62.8	33.7	2.3	1.2
Slovakia	3,067,090	1,901,610	71.7	27.3	1.0	0.0
Spain	30,042,210	23,300,220	48.5	34.2	17.3	0.0
Netherlands	2,008,870	1,847,570	56.2	41.8	2.0	0.0
Luxembourg	137,790	131,040	47.8	51.1	1.2	0.0
Italy	15,933,790	12,098,890	55.6	27.4	16.8	0.2
Poland	16,487,480	14,409,870	74.7	22.3	2.9	0.2
Bulgaria	5,608,980	4,650,940	70.5	27.3	2.0	0.1
Germany	18,305,150	16,699,580	71.1	27.7	1.2	0.0
Portugal	4,625,700	3,641,590	30.2	49.9	19.5	0.4
Lithuania	3,125,370	2,861,250	79.6	19.6	0.8	0.0
Latvia	3,058,780	1,877,720	64.1	34.8	0.4	0.7
France	29,264,400	27,739,430	66.6	29.7	3.7	0.0
Slovenia	902,160	485,760	71.7	27.3	1.0	0.0
Belgium	1,350,200	1,307,900	61.1	37.2	1.7	0.0
Greece	5,062,500	4,856,780	37.4	43.3	19.1	0.2
Malta	11,980	10,880	78.8	0.0	11.6	9.7
Croatia	1,728,100	1,571,200	55.9	39.3	4.6	0.1
Estonia	1,229,420	957,510	65.6	33.9	0.4	0.1
Finland	5,784,630	2,257,630	98.5	1.4	0.2	0.0
Sweden	6,424,370	3,035,920	85.1	14.8	0.2	0.0
Cyprus	123,810	109,330	73.3	1.7	25.0	0.0

Utilisation of agriculture area in Europe

Table 3 shows the agricultural area, utilised agricultural area (UAA) and proportion of UAA for EU28 in 2013. Total agriculture area covers over 213 million hectares of which over 174 million hectares are used for agriculture (most of the other area is used for woodland).

On average, 59.8% of the UAA was used for arable crops, with the highest percentages in Finland (98.5%), Denmark (91.5%), Sweden (85.1%), Hungary (81.6%) and Lithuania (79.5%). The EU countries with the lowest proportion of UAA devoted to arable cropping were Ireland (21%), Portugal (30.2%), United Kingdom (36.7%), Greece (37.4%) and Luxembourg (47.8%). The share of permanent grassland and meadow, associated with livestock rearing (notably dairy and sheep farming), exceeded 50% in Ireland (79%), United Kingdom (63.1%) and Luxembourg (55.6%), but was less than 10% in Malta (0%), Finland (1.4%), Cyprus (1.7%) and Denmark (7.5%). Permanent crops accounted for more than 10% of the UAA in the southern member states associated with the growing of grapes, olives and citrus fruits. The greatest percentage of land utilised for permanent crops was recorded in Cyprus (25.0%).

Maize for silage is an important crop and occupied 5.3 million hectares of land or 3% of the UAA. About 58% of the total area dedicated to maize silage was in Germany and France. Maize silage production accounts for a large percentage of UAA in Belgium (13.1%), the Netherlands (12.5%), Luxemburg (9.9%) and Germany (9.7%). In comparative terms, it represents more than 20% of the grassland area in Belgium, the Netherlands, Denmark and Germany, including the west of France.

Changes in permanent grassland areas in Europe

Between 1970 and 2013, 5.9 million hectares of grassland in the EU9 were lost to other purposes (Table 4), equating to a 15.3% reduction in the proportion of permanent grassland. During this period, the proportion of permanent grassland reduced significantly in Germany (31.8%), the Netherlands (30.1%), France (28.1%), Denmark (25.9%) and Belgium (21.7%); while the reduction in Italy was much lower (13.3%). There was a small reduction in Ireland (2.2%) and Luxembourg (0.8%), while there was an increase in the United Kingdom (6.4%). Similar reductions accrued in Austria, Greece, Spain and Hungary.

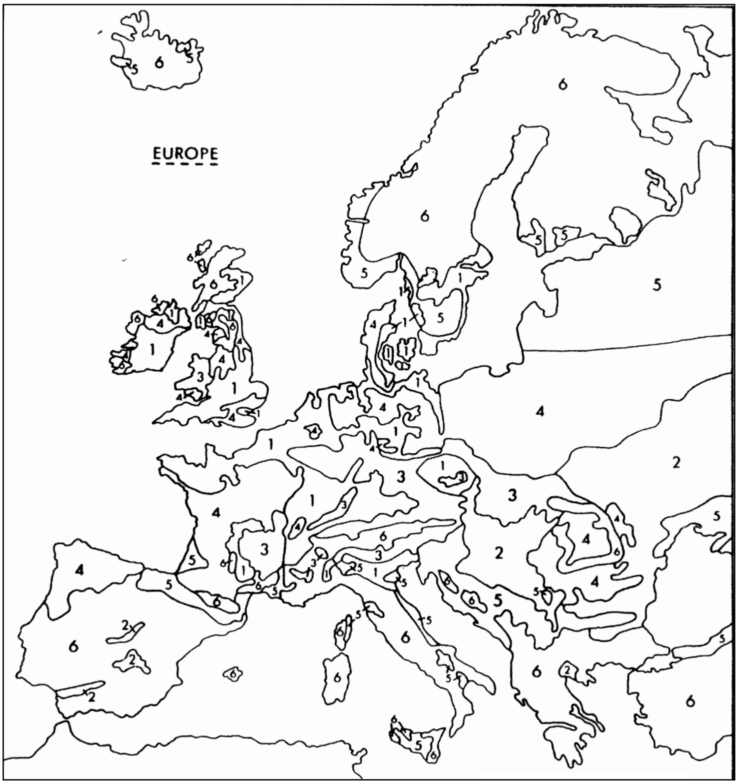
Potential and actual productivity of permanent grassland across Europe

Data on grassland productivity and its spatial distribution are scarce. Grassland productivity will be affected by botanical composition, soil characteristics, climate conditions, altitude, latitude and management (De Vliegher and Carlier, 2007). Lee (1983) reviewed grassland potential productivity data from most European countries. He divided Europe into five major geographical/climatic regions: (1) north-west and west Europe; (2) central Europe; (3) south-east Europe; (4) Mediterranean Europe and (5) northern Europe and Europe USSR. Factors considered to influence productivity were altitude, water stress, temperature and aspects such as slope, soil depth, etc. He concluded that grassland productivity in Europe was closely associated with precipitation amounts, with moisture stresses being a major constraint in the Mediterranean region (Figure 1). The map itself is considered by the author as the first approximation of European grassland production potential.

Hume and Corrall (1986) attempted to create a map of potential production for both irrigated and non-irrigated grassland in Europe using data from meteorological network and a grass growth model. This

Table 4. Changes in the proportion of UAA in permanent grassland area in EU9 between 1970 and 2013 (authors own calculations based on Eurostat).

	Total UAA	1970		2013	
		Permanent grassland (ha)	Proportion (%)	Permanent grassland (ha)	Proportion (%)
Belgium	1,307,900	621,253	47.5	486,539	37.2
Denmark	2,619,340	264,553	10.1	196,451	7.5
France	27,739,430	11,456,385	41.3	8,238,611	29.7
Luxembourg	131,040	67,486	51.5	66,961	51.1
Germany	16,699,580	6,780,029	40.6	4,625,784	27.7
Ireland	4,959,450	4,007,236	80.8	3,917,966	79
Italy	12,098,890	3,823,249	31.6	3,315,096	27.4
Netherlands	1,847,570	1,104,847	59.8	772,284	41.8
United Kingdom	17,096,170	10,138,029	59.3	10,787,683	63.1
Total	84,499,370	38,263,066	46.9	32,407,374	40.5



Land system		Limitation	Yield (kg DM ha^{-1})	
			Rainfed	Irrigated
1	Predominantly upland and lowland	Relatively few, some moisture stress and slope	10,000-15,000	
2	Predominantly lowland	Moisture stress	4,000-6,000	8,000-20,000
3	Predominantly hill land	Slope, depth, stoniness, some moisture stress	6,000-10,000	
4	Lowland (E. Europe) Upland (W. Europe)	Moisture stress, wetness, temperature	4,000-8,000	
5	Lowland, hill land	Severe moisture stress, temperature	2,000-6,000	
6	Upland, high mountain also lowland	Very severe moisture stress, temperature, altitude	800-3,000	

Figure 1. Potential productivity data from most European countries (Lee, 1983).

model was able to take water stress into account. However, they underestimated the drought effect in the non-irrigated swards model as indicated by not highlighting the Atlantic side between 52 and 57 degrees for maximum production.

A coordinated experiment organised by A.J. Carroll under the auspices of the FAO Lowland Grassland Sub-network measured the production and productivity of cutting grassland according to a standardised protocol in 32 European sites. The average annual production ranged from 10 to 14 t DM ha^{-1}. The extremes in grass production were very different ranging from 2 t DM ha^{-1} in Portugal to 20 t DM ha^{-1} in Germany (Kiel) (Peeters and Kopec, 1996). The most productive sites (>15 t DM ha^{-1}) were located on the Atlantic side of Europe between 52 and 57° N latitude. These included the Netherlands, Great Britain, Ireland, Belgium, north-western France and northern Germany. The less productive sites were situated at

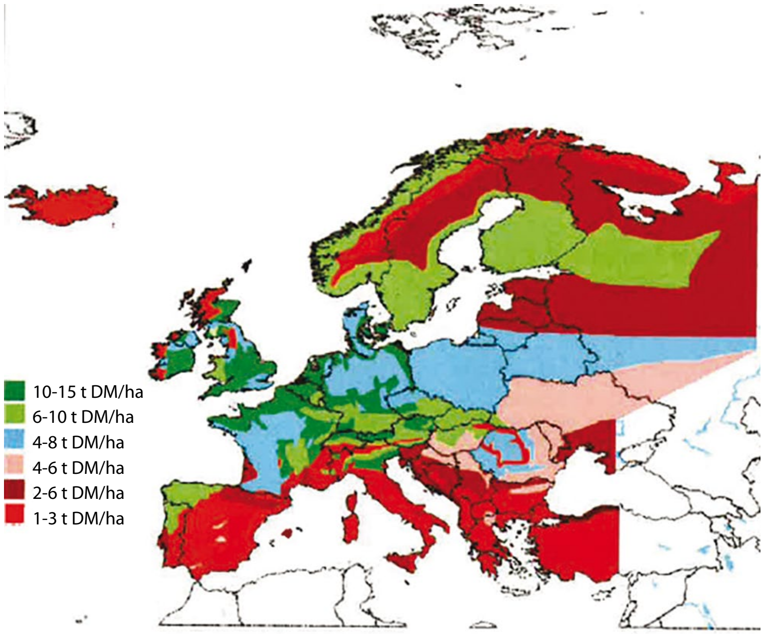


Figure 2. Production potential (annual yields in t DM ha^{-1}) of mown and heavily fertilised grasslands (Peeters and Kopec, 1996).

high or low latitudes in Europe. At high latitudes, production was limited by low temperatures and low levels of photosynthetically active radiation; in Portugal water stress limited production during summer. A synthesis of all this information has been made by Peeters and Kopec (1996) as presented in Figure 2.

Smit *et al.* (2008) presented spatial data of actual grassland productivity across regions in Europe, based on an extended set of regional, national and international statistics for Europe over a 10 year period (1995 - 2004). This study focused on green fodder from permanent grassland that included permanent pasture (herbages and rough grazing) and permanent meadows. It was the first study to synthesize grassland yields at a European scale. The highest productivity, about 10 t DM ha^{-1}, was obtained in north western Spain, western France, Ireland, Wales, England, the Benelux, northern Germany and south western parts of Norway (Figure 3). The highest yields recorded were in the Netherlands, regional grassland data was not available for Belgium and the country average was used. However, only grass production harvested for conservation was used, therefore, underestimating the productivity of the lowlands of Flanders. The lowest productivity occurred in the Mediterranean countries due to severe moisture stress with annual yields limited to 1.5 t DM ha^{-1}. In mountain regions and especially regions where irrigation is applied, much higher yields are obtained. Northern Europe (Iceland, north of Scandinavia and Russia) formed other low productivity regions. Countries in central Europe; like Germany, northern parts of Austria and Switzerland reached yields of greater than 6 t DM ha^{-1}; however, yields in the upper parts of the Alps were much lower. Grassland yields in Poland, Czech Republic and Slovakia reached about 4 t DM ha^{-1}. Yields in Hungary, Bulgaria, Russia and Ukraine were low, around 1.5 t DM ha^{-1} due to severe moisture stress; higher yields can be obtained in mountainous regions due to greater precipitation.

Grazing season length and impact of climate change

Grazing season length is an important parameter when defining ruminant production systems. A long grazing season can increase the annual proportion of grazed grass in ruminant's diets, which can reduce feed costs and thereby, increase profitability (Dillon *et al.,* 2005; Peeters, 2009; Finneran *et al.,* 2012).

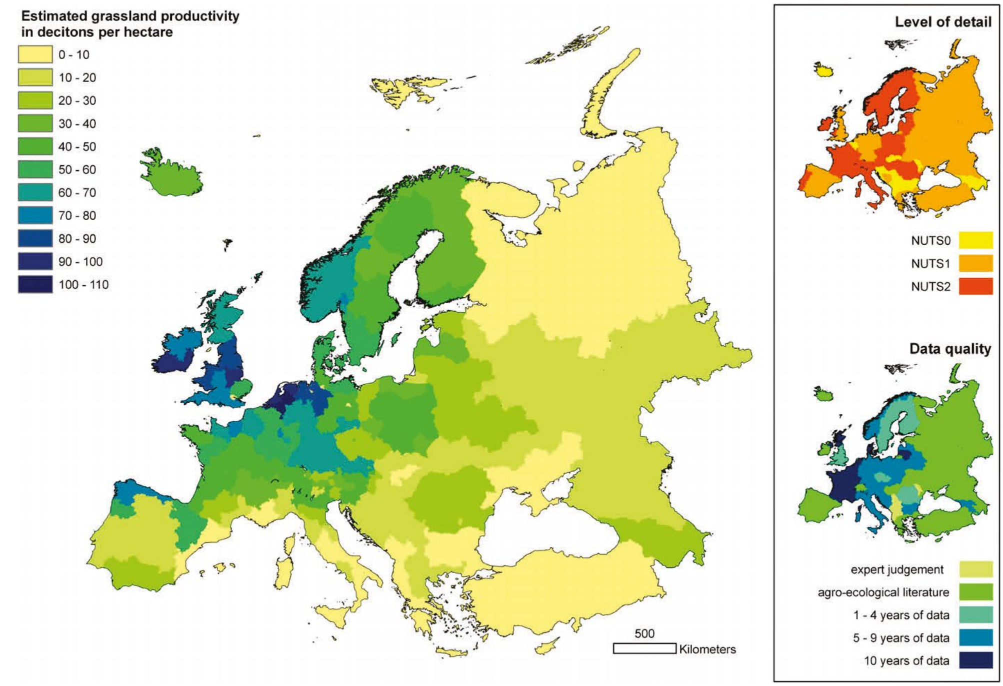


Figure 3. Spatial distribution of grassland productivity (dt ha^{-1}) in Europe. NUTS, Nomenclature of Territorial Units for Statistics (Smit *et al*., 2008).

It is also generally positively perceived by consumers when compared to indoor feeding systems (Font i Furnols *et al.,* 2011). Phelan *et al.* (2015) investigated the spatial variation in grazing season lengths from 32 European countries obtained from the results of the EUROSTAT Survey on Agricultural Production Methods (SAPM) and bioclimatic variables for dairy farms. The reference year was 2012 for all countries with the exception of Spain and Portugal which had 2009 as the reference year. Grazing season length was positively correlated with mean temperature during the coldest quarter and negatively correlated with precipitation in the wettest month. Figure 4 illustrates the observed and predicated grazing season lengths for dairy farms in all 32 European countries. The predicted grazing season lengths were longer than observed in Belgium, Estonia, Germany, Hungary and the Netherlands but shorter for Bulgaria, France, Latvia and Lithuania.

These significant relationships were subsequently used to predict future changes in grazing season length as influenced by climate change projections based on the most recent IPCC AR5 (Intergovernmental Panel on Climate Change, Fifth Assessment Report) (Jones *et al*., 2011; Taylor *et al*., 2012). Future projections were carried out for 2050 (mean of 2041 - 2060) and 2070 (mean of 2061 - 2080) using a concentration pathway of 2.6, 4.5, 6.0 and 8.5 W m^{-2}. The analysis predicts that grazing season length would increase from the observed average of 6.1 months in 2012 to 6.7 months in 2050 and 6.8 months in 2070 (Figure 5). However, both increases and decreases were predicted within different regions of some countries such as France, Norway, Germany, Italy, Spain and UK. The greatest reduction in grazing season lengths was predicted for the west of France, south-west Norway and west coast of Britain.

Contribution of ruminant production from grassland to food security

Human population is expected to increase from 7.2 to 9.6 billion by 2050 (UN, 2013). This represents a population increase of 33%, but as the global standards of living increases, demand for agricultural

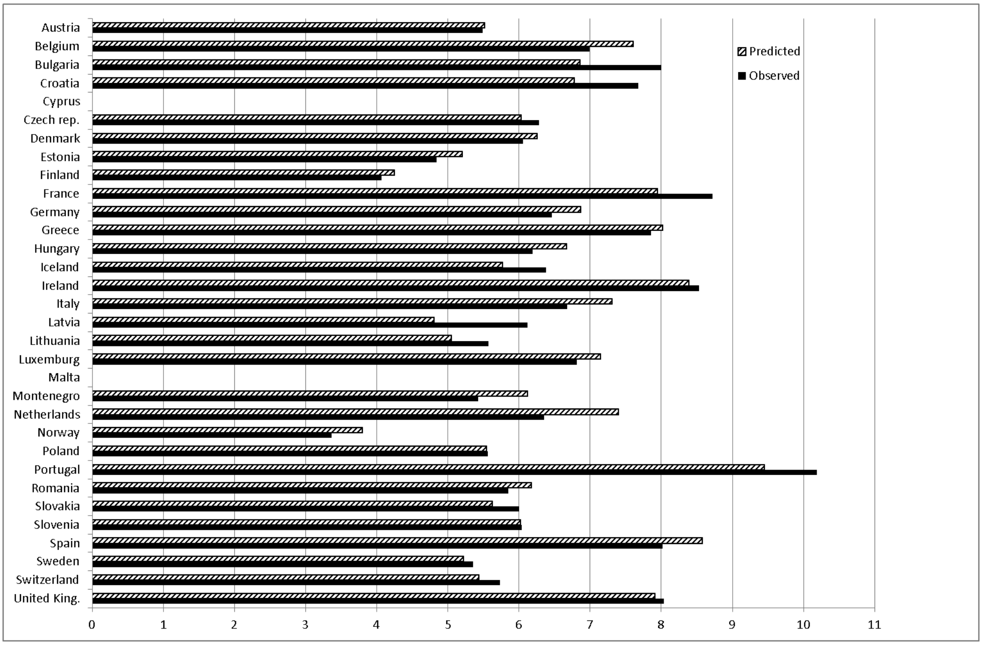


Figure 4. Observed and predicted grazing season length (months) for 32 European countries (Phelan *et al*., 2015).

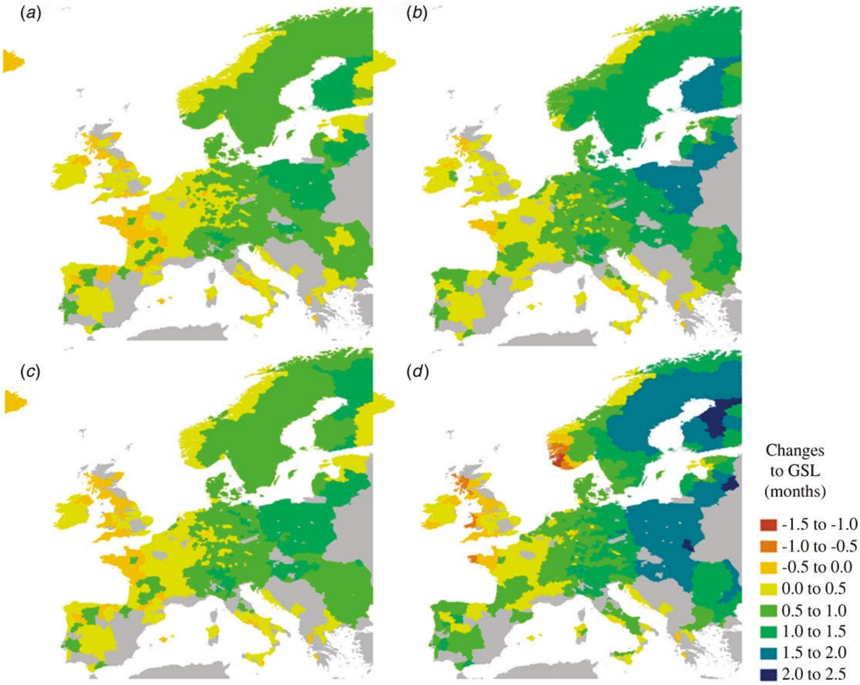


Figure 5. Maps of predicted future changes to grazing season length (GSL; months) on dairy farms under the CMIP5 HadGEM2-ESclimate change scenarios for 2050 (a, b) and 2070 (c, d) under representative concentration pathways 2·5 (a, c) and 8·5 (b, d) (Phelan *et al*., 2015).

products will increase by about 70% in the same period (FAO, 2009). Livestock products are important agricultural commodities for global food security because they produce 17% of global kilocalorie consumption and 33% of global protein consumption (Rosegrant *et al.*, 2009). Worldwide, it is expected that milk production will increase from 644 million tonnes (in 2006) to 1,077 million tonnes (by 2050) and meat production will double from 258 to 455 million tonnes (Alexandratos and Bruinsma, 2012). However, livestock production uses 75% of grassland land (Foley *et al.*, 2011) of which one third of the land area is arable and two thirds are grasslands and rangelands (Steinfeld *et al.*, 2006), consumes 35% of grain products (Alexandratos and Bruinsma 2012) and emits 14.5% of global greenhouse emissions (Gerber *et al.*, 2013).

Livestock are often perceived as having a negative effect on food security as: (1) animals are fed rations containing products that can also serve directly as human food; (2) animal feed may be produced on land suitable for human food production; and (3) the efficiency of animals in converting feed into human edible products is relatively low. In reality, livestock also play an important role by converting forages, crop residues and agricultural by-products that are not human edible into high quality human edible food. The literature often highlights the supposed efficiency of pigs and poultry in converting feed into meat; but these studies do not take into account the higher share of feed consumed in the form of grains that are edible by humans and the use of land suitable for human food production that is required in modern monogastric feeding systems. Mottet *et al.* (2017) estimated that the production of 1 kg of boneless meat requires 2.8 kg of human edible feed in ruminant systems and 3.2 in monogastric systems. These global figures, however, conceal a vast range of feed conversion ratios and feed qualities, between and within species and production systems.

The drive to increase the output of animal products in some sectors of ruminant livestock production has led to greater use of feeds such as cereal grains and soybean meal that are potentially human-edible. This trend has caused concern since, by doing so, ruminants compete not only with monogastric livestock but also with the human population for a limited global area of cultivated land on which to produce grain crops. The amount of edible protein of animal origin produced per kg of human edible protein of plant origin is an unbiased view of the contribution of livestock to food security (Wilkins, 2011). If the ratio is greater than 1.0, the animal production system contributes to food security; if the ratio is less than 1.0, the production system contributes negatively to food security. Wilkins (2011) showed that in UK livestock systems, grassland based dairy systems were the most efficient producing up to 1.4 kg of milk protein per kg of edible protein of plant origin. Conversely, the least efficient were intensive beef production (0.30), broilers and pig (0.47) and egg production (0.38 to 0.43). Recent analysis of French dairy production systems showed that more intensive systems using a lot of maize silage and concentrates were less efficient in terms of milk protein per kg of edible plant protein (Laisse *et al.*, 2016). Analysis of National Farm Survey data in Ireland showed that the average Irish dairy farm had an efficiency of 1.5 kg of milk protein per kg of edible plant protein (Hennessy and Moran, 2014). More extensive pasture-based systems around the world make a significant contribution to protein security (Bradford *el al.*, 1999).

Opportunities to further increase the efficiency of European grass-based systems of livestock production

The competitiveness of grass-based systems of ruminant production can be further improved through the adoption of technologies. These are briefly summarised:

- Grass-breeding and evaluation: In Europe, grass breeders have increased DM yield by 0.5% per year as tested in cutting trials in the Netherlands from 1965 to 1990 (Van Wijk and Reheul, 1991). There is little evidence, however, that new grass/clover cultivars have made a significant contribution to increased animal production. Presently, plant evaluation systems measure grass DM yields using a simulated cutting/grazing protocol over a two to three year period; this needs to be changed to an on-farm cultivar evaluation protocol based on lifetime performance. The recent development of the Pasture Profit Index in Ireland and the Forage Value Index in New Zealand and Australia are significant progress in this area. In addition, there is a clear requirement for greater selection emphasis on characteristics that influence animal performance such as herbage intake and DM digestibility; this will require the development of new feed chemistry analysis to better reflect the true nutritional value. This can be best achieved by adopting interdisciplinary initiatives among plant physiologists, nutritionists, plant breeders and evaluators sharing knowledge and resources. There is also a requirement to introduce new breeding technologies into breeding programmes such as genomic technologies to accelerate genetic gain.

- Animal genotype: The animal required for efficient pasture-based systems must be robust, autonomous, 'easy care' and capable of a high level of performance (milk production/composition; reproductive performance; maintain adequate body reserves; avoid ill health) from a predominantly grazed pasture diet. There is now strong evidence to show that dairy cows that are genetically best suited to non-grazing systems are not best suited to grazing systems from studies carried out in Ireland (Dillon *et al*., 2006) and France (Baumont *et al*., 2014), indicating an interaction between genotype and feeding system. Successful grazing systems require dairy and beef cows that are capable of achieving large intakes of forage relative to their genetic potential for milk production (i.e. aggressive grazers), are extremely fertile to facilitate compact calving at the start of the grass growing season, survive for 5.5 lactations, have a high health status, and are easy care and robust to fluctuations in feed supply.
- Sward species composition: Huyghe *et al*. (2012) showed that a positive relationship between species diversity in sown swards and biomass production is frequently found in controlled environments. Introducing legume species into conserved and grazed swards gives many advantages relating to feed value, animal performance and environmental impact. White clover has a high digestibility and a high energy value; this is attributed to its low fibre concentration which reflects the absence of structural components such as stem and sheaths (Ayres *et al.,* 1998). A particular advantage of white clover is the reduced rate of decline in digestibility in mid-season compared to perennial ryegrass (Ulyatt, 1970). Increased production performance by incorporating white clover into pastures has been observed in dairy cows (McCarthy *et al,* 2017; Hennessy *et al.,* 2017), beef steers (Thomas *et a*l., 1981) and sheep (Orr *et al*., 1990). Despite the clear advantages in animal performance of perennial ryegrass/white clover pasture over perennial ryegrass only pasture, there are issues that need to be considered such as increased prevalence of bloat and additional ancillary costs associated with maintaining swards high in white clover content.
- Increase sustainability: The goal of producing more food from the same land area, while reducing environmental impact, has been termed 'sustainable intensification' (Pretty, 1997) or 'ecological intensification' (Griffon, 2013). Pasture-based systems have been shown to be beneficial to the environment (Jankowsaka-Huflejt, 2006; Peyraud *et al.,* 2010) and in reducing the costs of production (Dillon *et al.,* 2005). It has been generally accepted that increased stocking rates (cows ha^{-1}) and milk output per hectare will lead to greater N loss to groundwater. Two recent pasture-based studies, one in Ireland (Huebsch *et al.,* 2013) and the other in New Zealand (Roche *et al.,* 2016) have shown that higher stocking rates with increased milk output per ha can be achieved alongside low N losses to ground water. Similar to the de Marke farm in the Netherlands (Hilhorst *et al*., 2001), a large number of changes to management practices contributed to this overall effect including increased grazed grass utilisation; greater use of organic manures to replace chemical fertiliser; more strategic use of chemical N; reduced cultivation reseeding methodologies; improved grazing management and nutrient budgeting and the preferential management of higher risk farm areas. The carbon footprint of both milk and meat can be reduced by increasing the genetic merit of dairy cattle, maximising the use of grazed grass and strategic timing and application of slurry and chemical fertiliser (O'Brien *et al*., 2014).

- Grazing management practices: In recent years the development of reliable, easy to use web based decision support tools has facilitated improved feed budgeting and grazing management on grassland farms (e.g. PastureBase Ireland). It was not until the 1970's that the relationship between milk yield and pasture allowance was identified (Hodgson, 1975). O'Donovan (2000) developed targets for average pasture grass cover. More recently, specific grazing management technologies have been developed to improve grazing management within specific periods (spring, mid-season and autumn). The Spring Rotation Planner is used from turnout until grass growth equals herd demand; the Pasture Wedge is used to control grass supply during mid-season taking into account herd demand, rotation length and post-grazing residual; and Autumn Feed Budgets are used to maximise the amount of grazed grass utilised while at the same time ensuring that the grazing season is extended into late-November/early-December with the desired farm grass cover. The development of reliable, easy to use decision support tools will allow grassland farmers to put greater reliance on grazed pasture and will provide greater connection between researchers, extension advisors and grassland farmers.

Grass grows more regularly from spring to autumn in western Europe (e.g. UK, Ireland, northwest of France), whereas in other regions grass does not grow in summer (Pays de Loire and Aquitaine in France) or the grazing season is quite short due to long, cold winters (Northern countries). Eighty one percent of European grassland and 44% of total livestock are located in less favoured areas (LFAs) that include the grassland ecosystems most threatened due to abandonment as total livestock numbers decline. Opportunities should be sought to integrate these high biodiversity grasslands into commercial productive grasslands. These less productive grasslands provide multiple functions that include protection of water quality, carbon sequestration in the soil, protection of soil from wind erosion and maintain biodiversity, hence, some of these grasslands have a high nature value. Although grazing management objectives differ, most are managed by commercial farmers and there is a significant opportunity to produce high quality human edible protein from a wide range of biomass using ruminant livestock.

Conclusion

Since the early 1970's, European grassland area has declined in favour of maize and other annual crops. There is a large variation in grassland productivity in Europe, influenced by climate conditions, soil characteristics, altitude, latitude and management. Grazing season length is positively correlated with mean temperature of the coldest quarter and negatively correlated with precipitation in the wettest month. Grazing season length is predicted to increase from an observed average of 6.1 months in 2012 to 6.7 months in 2050 and 6.8 months in 2070. Livestock play an important role in human food security by converting forages, crop residues and agricultural by-products that are not human edible into high quality human edible food. In the future there should be greater emphasis on the development of decision support tools that can help grassland farmers to make better management decisions with regards to grassland, animal and farm systems.

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Ruminant grassland production systems in Ireland

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Abstract
In Ireland, grazing systems provide the basis of sustainable livestock production, as grazed grass is the cheapest feed source of nutrients for ruminants. A key future objective for these systems is to ensure high grass utilisation, supporting increased output per hectare. Ireland's national farm policy targets growth in exports to €19 billion per annum by 2025. This figure represents an 85% increase from the current three year average. There are major improvements required in the areas of grassland management and its conversion to milk and meat products to fulfil such a target. While every farm situation is unique due to varying soil types, climatic conditions, stocking rates and management capabilities, grass production and utilisation are below optimum on most farms. Irish farms, especially dairy farms, are expanding and will continue to do so over the next number of years. Increasing stocking rates and more compact calving and lambing has resulted in increased spring feed demand. Extra grass needs to be grown and utilised in this period to minimise the use of supplementary feed. This paper outlines the importance of grassland on Irish farms, and where farms can improve grassland management, to increase output, lower farm costs and further improve farm system sustainability.

Keywords: grazing, ruminant production, grassland, dairy, beef, sheep, sustainability

Introduction
Grasslands contribute substantially to Irish agricultural production systems providing a large proportion of the feed requirements of ruminant livestock (O'Mara, 2008). Grassland in Ireland accounts for approximately 92% (3.91 million ha) of the agricultural land area (CSO, 2017) (Table 1). Rough grazing includes grazed un-reclaimable bogland and grazed mountain and lowland partially covered in scrub,

Table 1. Area farmed (×1000 ha) by type of land use and year (2013-2016).

	2013	2014	2015	2016
Area farmed (UAA[1])	4,477.8	4,465.8	4,429.5	4,447.2
Crops and pasture	4,004.3	3,971.5	3,926.0	3,914.8
Pasture	2,337.7	2,308.4	2,299.4	2,307.8
Hay	218.4	217.9	195.7	188.4
Grass silage	1,071.0	1,077.6	1,071.1	1,066.8
Maize silage	14.5	13.9	12.9	10.9
Fodder rape and kale	1.4	1.2	1.7	1.6
Beet	10.1	10.3	9.6	9.5
Other crops	4.7	4.0	5.8	7.7
Total cereals	307.8	306.7	292.4	281.1
Total wheat	60.6	71.6	65.3	67.9
Total oats	26.7	18.6	23.4	23.2
Total barley	219.4	215.7	202.8	189.2
Other cereals	1.1	0.8	0.9	0.8
Rough grazing in use	473.5	494.2	503.6	532.4

[1] Utilisable agricultural area.

bushes or rock (O'Mara, 2008). The average proportion of the total grass silage area (1.066 million ha) harvested for first, second and subsequent silage harvests is 78, 21 and 1%, respectively (O'Donovan *et al.*, 2011). The use of other crops, such as maize silage and beet, has declined in recent years. Irish grassland can produce some of the highest non-irrigated herbage yields (12 - 16 t DM ha^{-1} per annum) in Europe (O'Donovan *et al.*, 2011).

Table 2 shows livestock numbers in Ireland for the past five years. Total cattle numbers have increased by 461,000 head. The substantial increase in this number has been generated from the increase in the number of dairy cow (+269,000); while suckler cow numbers have decreased (-69,000) in the same period. Increases in younger stock numbers have also taken place in line with the overall increase in maternal cattle numbers. Total sheep numbers have increased by 245,900 in the period; however, the number of breeding ewes has declined by 57,000, which shows an increase in the efficiency of the sheep flock.

The increase in dairy cow numbers has been greatest in the south east and west of the country, which have seen the largest regional increases (+70,000 each). The western and border regions have recorded the most modest increases, 11,000 and 17,000, respectively. The largest reduction in suckler cow numbers has occurred in the south east (-15,000), while suckler cow numbers in the west have remained largely static. In the future, it is likely that suckler cow numbers will decline further and even in the current year, suckler cow numbers calving have declined by 3%.

Feed costs

Grazed grass is the most efficient feed for grass based ruminant production systems in Ireland. The relative cost of grazed grass is €75 t^{-1} utilisable (U) DM compared to first cut grass silage at €185 t^{-1} UDM, second cut grass silage at €182 t^{-1} UDM and rolled barley at €188 t^{-1} UDM (Finneran, 2010). Costs were calculated using a stocking rate of 2.5 livestock units (LU) ha^{-1} and herbage production of 13.5 t DM ha^{-1} as well as a land costs charge of €350 ha^{-1}, and feeds were compared on a UFL basis. The relative competitive advantage of grazed grass is expected to increase over the next number of years due to higher concentrate prices and the high cost of producing conserved feeds (grass and maize silage; costs include labour, energy and machinery costs).

Industry targets

The progress of the Irish ruminant sector has been assisted greatly by the positive Agriculture Policy of our Department of Agriculture, Food and Marine. Successive Agriculture Policy initiatives such as Food Harvest 2020 and currently Food Wise 2025 (DAFM, 2015) have identified Agriculture as a key sector

Table 2. Number of livestock (×1000 head) by type of animal and year (2013-2017).

	2013	2014	2015	2016	2017
Total cattle	6,902.6	6,926.1	6,963.5	7,221.2	7,363.5
Cows	2,313.5	2,355.4	2,371.6	2,501.6	2,513.6
Dairy cows	1,163.2	1,226.4	1,295.8	1,397.9	1,432.7
Suckler cows	1,150.3	1,129.0	1,075.8	1,103.7	1,081.0
Bulls	41.4	40.8	36.5	25.0	16.9
Cattle: 2 years and over	768.3	884.3	808.1	715.5	788.1
Cattle: 1 - 2 years	1,811.0	1,767.2	1,705.1	1,853.3	1,913.9
Cattle: under 1 year	1,968.5	1,878.4	2,042.2	2,125.9	2,130.9
Total sheep	5,007.0	5,096.8	5,138.7	5,179.2	5,252.9
Breeding sheep	2,648.6	2,591.3	2,563.9	2,582.8	2,591.5

for the growth of the Irish economy. The Food Wise 2025 report (DAFM, 2015) has identified both grass production and utilisation targets for Irish dairy production systems. In 2016, Gross Agricultural Output (GAO) was valued at €6.92 billion (DAFM, 2016), and in the same year, dairy and ingredients exports increased by 2% to €3.38 billion. The value of the beef industry to the economy is currently in excess of €2.38 billion. Annual beef output exceeds 535,000 t of which 90% is exported. Sheep production is also a significant contributor to the agricultural economy producing 61,000 t of sheep meat with an output value of €240 million in 2016. This is an increase in value of 4% compared to 2015, with a meat volume output increase of 3%. The 36,313 sheep flocks produce a high quality product with about 75 to 80% exported. Irish food and drink exports to China have increased six fold in six years, while exports to North America and the rest of Asia have doubled in the same period.

Every three years sectorial enterprise roadmaps (Table 3) are developed for the main ruminant industries (dairy, beef and sheep). These roadmaps provide very important targets for the sectors both in the next 10 years (2025 Target) and also over the longer term (Research Target) and act as guides to the industry. With the current expansion of the dairy milk pool, systems of milk production in Ireland can become more efficient through increased dairy cow fertility and better grass utilisation, i.e. more effective use of home grown feed. There is an expectation of and commitment from the industry to expand in a sustainable manner, which is underpinned by agricultural research in Ireland. In suckler beef production, reduced calving intervals and increased herbage utilisation (more grass in the diet) will together improve the efficiency of the sector. In the sheep sector, the key efficiency gains will come from increasing the number of lambs reared per ewe, increasing stocking rate and finally, maximising the use of grass and reducing the reliance on supplementary feeds. The common efficiency to be achieved across all sectors is increased grass utilisation.

Table 3. Dairy, suckler beef and sheep sector roadmaps for current performance, future performance targets up to 2025 and research targets.

	Current	2025 target	Research target
Dairy sector			
Milk delivered (kg cow^{-1})	5,036	5,739	5,800
Milk solids (fat + protein) delivered (kg cow^{-1})	372	448	475
Calving interval (days)	394	385	365
Stocking rate (LU ha^{-1})	1.96	2.15	2.94
Herbage utilised (t DM ha^{-1})	7.36	10.0	12.7
Concentrate per cow (kg)	1,008	750	400
Nitrogen fertiliser (kg N ha^{-1})	176	230	250
Greenhouse gas emissions (kg CO_2e kg^{-1} milk solids)	1.10	0.97	0.83
Suckler beef sector			
Calves cow^{-1} $year^{-1}$	0.81	0.85	0.95
Calving interval (days)	407	397	365
Herbage utilised (t DM ha^{-1})	5.6	6.2	11.3
Concentrate per LU (kg)	393	390	298
Nitrogen fertiliser (kg N ha^{-1})	129	145	210
Greenhouse gas emissions (kg CO_2e kg^{-1} carcass)	25.7	23.5	21.8
Sheep sector			
Lambs weaned ewe^{-1} $year^{-1}$	1.29	1.45	1.75
Stocking rate (ewe ha^{-1})	7.3	9	12
Concentrate input (kg ewe^{-1})	90	50	35
Lambs drafted by October 1 (%)	71	70	65
Nitrogen fertiliser (kg N ha^{-1})	69	99	132

Farm system sustainability

Farm system sustainability is achieved under the three pillars of economic, social and environmental sustainability. The production system must be profitable, afford a good work-life balance with family life, and provide a good working environment for the farmers and any staff that are directly employed in the business.

Grass based systems are more resource efficient as they use home grown feed stuffs and minimise the requirements for purchased feedstuffs and therefore, the resources (land, labour, energy and machinery) associated with those feedstuffs. One of the key challenges facing agriculture today in Ireland, and in Europe, is centred on the requirement to reduce environmental losses and impacts. In Ireland and Western Europe, grassland has a high capacity to capture nitrogen (N) as grass is present year round and grass is actively growing for a large part (10 to 12 months) of the year.

Future grass based milk and meat production systems will need to minimise nutrient losses (e.g. N and phosphorus (P)) to water and gaseous emissions (GHG, ammonia) to the atmosphere, so that production systems operate in an acceptable way to society as a whole (i.e. good animal welfare, preservation of the ecosystem, landscape, biodiversity). In 2015, national N fertiliser application was 129 and 39 kg ha^{-1} on dairy and beef farms, respectively, and an average of 63 kg N ha^{-1} for all agricultural enterprises including tillage (Wall and Dillon, 2017). Inputs of P fertiliser were 4 and 9 kg ha^{-1} and potassium (K) fertiliser were 9 and 21 kg K ha^{-1} for beef and dairy farms, respectively, in 2015.There has been a continual decline in fertiliser N input since 2005 (average 82 kg ha^{-1}) to date. From this analysis, it is clear that Irish livestock farms are low chemical fertiliser input systems and, in fact, are not applying enough P and K to maintain adequate soil fertility levels.

The most recent research (O'Brien *et al*., 2017) shows that on NFS farms, the average carbon footprint of milk from Irish farms decreased from 1.17 to 1.04 kg CO_2- equivalent kg^{-1} of fat and protein corrected milk (FPCM) from 2013 to 2015. This reduction in the average footprint was largely due to an increase in milk solids yield ha^{-1} and a decline in concentrate feeding. This led to a reduction in animal methane emissions, and carbon dioxide and nitrous oxide from feed production.

Increased demand for grass on farm

Major improvements are required in grazing management and the conversion of grass into milk and meat products. While every farm situation is unique with varying soil types, local climatic conditions, stocking rates and farmer management capabilities, grass production is below optimum on most farms. Irish dairy farms have expanded rapidly over the last number of years; average herd size is now approximately 82 cows per farm. Increased herd size requires additional herbage supply (i.e. grass growth) to meet an increasing herd demand. Increasing stocking rates (an additional 100,000 cows calved in spring 2016; ICBF, 2016) and compactness of calving (a reduction in mean calving date of five days and an improvement in six week calving rate of 6% from 2011 to 2015; ICBF, 2016) (Figure 1) has increased spring feed demand on dairy farms. Increases in ewe stocking rate (+ 4%) and weaning rate (+ 8%) and a resultant increase in carcass output ha^{-1} (+ 15%) relative to the five year average, as shown in Table 4, is also increasing the demand for grass on Irish sheep farms. Extra grass must be grown and utilised in spring to avoid increases in supplementary feed use. Teagasc National Farm Survey data from the last two years shows that farms targeting high levels of grass utilisation are more profitable (+ €171 and €105 ha^{-1} of net farm profit per each additional 1 t grass DM utilised ha^{-1} on dairy and beef farms, respectively).

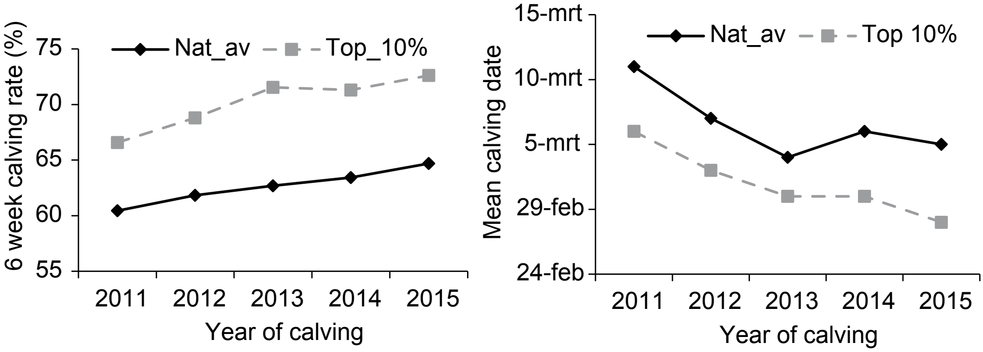

Figure 1. Trends for mean calving date and 6 week calving rate for cows in the top 10% (broken grey line) and national average (solid black line) Economic Breeding Index.

Table 4. National Farm Survey technical performance indicators on Irish sheep farms 2011 to 2016.

	2011	2012	2013	2014	2015	2016
Stocking rate (ewes ha^{-1})	7.2	7.2	7.5	7.6	7.4	7.7
Weaning rate (lambs ha^{-1})	1.3	1.2	1.3	1.3	1.3	1.4
Lamb carcass (kg ha^{-1})	187	175	189	202	193	217

Herbage production on Irish farms – PastureBase Ireland data (2013-2017)

There is significant variation in grass DM production on farms. This is one of the key early findings emerging from the analyses of data captured in PastureBase Ireland (www.pasturebaseIreland.ie; Hanrahan *et al.*, 2017). There are many reasons for this, including differences in stocking rate, soil fertility and grazing management practices. If soil fertility and grazing management can be improved, many farms are very capable of increasing herbage production. High grass DM production can be achieved on dairy and drystock farms, irrespective of location, through good grazing management, soil fertility management, good grazing infrastructure and use of perennial ryegrass + white clover swards.

Figure 2 and 3 show the annual DM production data from dairy and drystock farms across Ireland in 2016. These farmers have recorded > 30 weekly farm walks (weekly assessment and recording of herbage mass present on all paddocks on the farm). In 2013, these farms produced an average of 12.2 t DM ha^{-1}. This increased to 13.5 t DM ha^{-1} in 2014, highlighting the year effect on grass growth. The variation between farms is very high; the difference between the lowest and highest producing farms was 9.4 t DM ha^{-1}. An important aspect of the grass production data is that the highest producing farms are growing in excess of 16.0 t DM ha^{-1}, with little variation between paddocks. In 2015, there was an increase of 0.6 t DM ha^{-1} compared to the previous year; on average dairy farms grew 14.1 t DM ha^{-1}. Much of the extra herbage produced in 2015 was grown by April, and the mid-year grass growth profile was consistent with 2014. After a period of slow grass growth in spring 2016, growth recovered well in May, however, there was 0.3 t DM ha^{-1} reduction in DM production with the average dairy farm producing 13.8 t DM ha^{-1}.

Increased herbage production is necessary to meet the increased feed demand on farms as stocking rate increases. Increases in stocking rate have occurred predominantly on dairy farms and to a lesser extent on intensive beef and sheep farms. The optimum stocking rate for an individual farm is that which gives sustainable profitability and is dependent on the individual farms grass growth capability. Many Irish farms are only achieving 50 - 60% of their grass growth potential. Research studies looking at the effect of increasing stocking rate on grass production and utilisation within both dairy (McCarthy *et al.*, 2012)

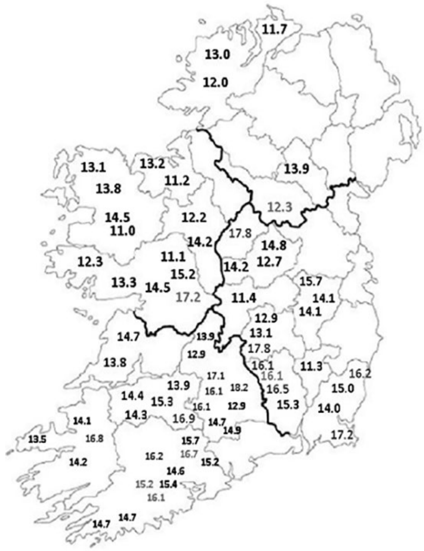

Figure 2. Grass dry matter production from PastureBase Ireland dairy farms across the country in 2016.

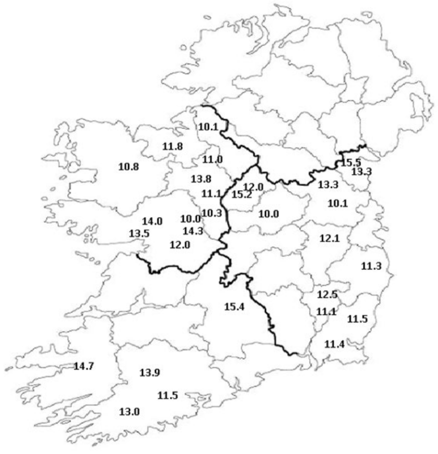

Figure 3. Grass dry matter production from PastureBase Ireland drystock farms across the country in 2016.

and sheep systems (Earle *et al*., 2017) show great potential to increase farm productivity and demonstrate that dairy and drystock systems are equally capable of growing and utilising increased levels of grass at farm level. A recent survey of high performing grassland farmers found that they all agreed that they were completing more farm walks, grazing their livestock to lower post grazing heights and reseeding more than they were five years ago. This shows that continuous improvement in grazing management practice can result in increased herbage production.

Increase in stocking rate

Published data shows that Irish dairy farms are growing 9.1 t DM ha^{-1} (McEvoy *et al*., 2011) over an average of a 220 day grazing season. More recent data shows that drystock farms that are measuring grass routinely are growing 12.2 t DM ha^{-1} (O'Donovan *et al*., 2016). Comparing these figures to the PastureBase Ireland dataset, on average, the bottom 20% of farms are growing 11.0 t DM ha^{-1}, the average farms are growing 13.8 t DM ha^{-1}, while the top 20% of farms are growing 16.7 t DM ha^{-1} (Figure 2). The variation in seasonal herbage production on PastureBase Ireland farms is as follows: 816 - 1,199 kg DM ha^{-1}in spring, 4,462 - 4,932 kg DM ha^{-1} in mid-season and 5,937 - 6,442 kg DM ha^{-1}in autumn. There is a strong relationship between the number of grazings per year and herbage production (Figure 4); in fact, the farms producing the greatest quantity of herbage are achieving an extra grazing per year compared to the farms producing the least (7.7 and 6.8 grazings per paddock per year, respectively). The extra grazing results in more grass in the diet of grazing livestock, reducing the requirement of supplement and providing an extra 20 grazing days per year.

Grass and clover systems

Forage legumes, and white clover (*Trifolium repens* L., clover) in particular, have the potential to positively influence the sustainability of pasture-based ruminant production systems and this has driven increased interest in the use of clover in Ireland. A recent meta-analysis (Dineen *et al*., 2017) to quantify the milk production response associated with the introduction of clover into perennial ryegrass (*Lolium perenne* L.) swards, found that at a mean sward clover content of 31.6%, mean daily milk and milk solids

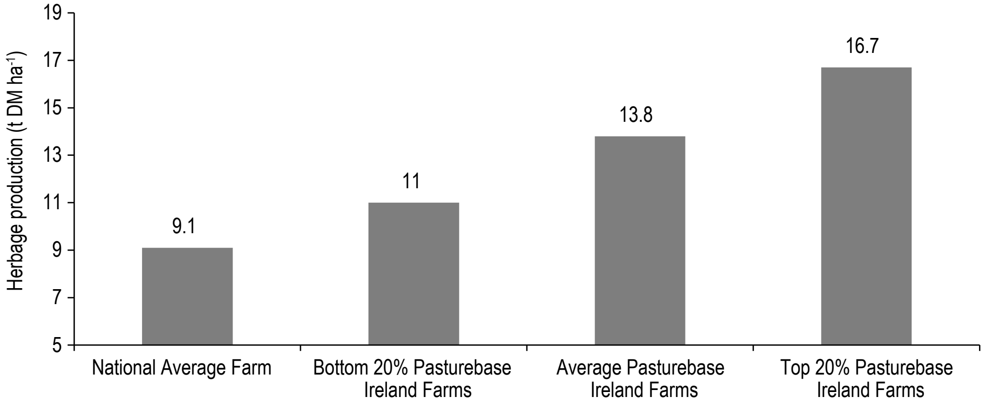

Figure 4. Average herbage production of national average dairy farms and farms in the bottom 20%, average and top 20% recording into PastureBase Ireland.

yield per cow were significantly increased by 1.4 and 0.12 kg, respectively, compared to grass only, but there was no significant effect on milk yield and milk solids yield per ha. Stocking rate and N fertiliser application were reduced by 0.25 cows ha^{-1} and 81 kg ha^{-1} respectively, on grass + clover (3.32 cows ha^{-1}) swards compared with grass only (3.57 cows ha^{-1}) swards. The most recent grass-clover experimental work in Ireland completed at Teagasc Moorepark and Clonakilty has shown clear advantages of combining perennial ryegrass and clover compared to perennial ryegrass only. Dineen (2017) reported that over a two year period, at the same stocking rate (2.75 cows ha^{-1}) and N fertiliser application rate (250 kg N ha^{-1}), cows grazing grass + clover produced an additional 647 kg of milk and 55 kg milk solids per cow, compared to cows grazing grass only, which equated to an additional 1,781 kg milk and 151 kg milk solids ha^{-1}. In addition, total herbage production was 2.5 t DM ha^{-1} greater on grass + clover swards compared to grass-only swards, although it is expected that these differences are likely to decline over a longer time period. Another farm systems experiment was undertaken at Teagasc, AGRIC, Moorepark, Ireland from 2013 to 2016. The experiment compared herbage and milk production from a grass-only sward receiving 250 kg N ha^{-1} per year and grass-clover swards receiving 250 or 150 kg N ha^{-1} per year (Hennessy *et al*., 2017). Each treatment was stocked at 2.74 cows ha^{-1}. Annual herbage production was similar on all treatments (14.6 t DM ha^{-1}) across the four years of the experiment. Average annual sward clover content was greater on clover receiving 150 kg N (27%) compared with clover receiving 250 kg N (23%). Milk solids yield was greater on the two clover treatments (495 kg MS cow^{-1} year^{-1}, respectively) compared with the grass-only treatment (460 kg MS cow^{-1} year^{-1}).

Improved delivery from grass breeding and evaluation systems

Perennial ryegrass forms the basis of grassland production in Ireland and is the most important forage. Over 95% (3,624 t) of all forage seed sold in Ireland is perennial ryegrass, and 4% (140 t) is white clover. There has been large investment by the plant breeding industry in producing new varieties and independent testing systems designed to identify and list those varieties with the most improved performances over the past 40 years. McDonagh *et al.* (2016) compared the DM yield and sward density of new grass varieties submitted for evaluation from 1973 to 2013, and grass digestibility of grass varieties from 1980 to 2013, under conservation and simulated grazing managements. Dry matter yields showed an overall significant (P < 0.001) average annual increase of 0.52% under conservation and 0.35% under simulated grazing, with similar levels of gain within maturity groups and ploidy. These rates were not constant over time, and periods of no gain occurred in various variety groupings. Sward density did not change significantly in the study period. Herbage digestibility showed no improvement over the timeframe but exhibited the largest differences between concurrent varieties, indicating that future improvements were possible. The study indicated that plant breeding gains were primarily focused on DM yield, with sward density remaining stagnant over the 40 years, while the lack of grass digestibility improvement appeared to only require more time to overcome.

The introduction of the Pasture Profit Index (McEvoy *et al*., 2011; O'Donovan *et al*., 2017; PPI) into the Irish Recommended List for Grass and Clover, combined with the change to evaluation under intensive simulated grazing protocols and more on farm grass and clover variety evaluation using PastureBase Ireland will bridge the gap between farmers, evaluation and breeding. Although there is a general consensus amongst breeders internationally that individual varieties can perform well in a range of environments, the evidence from the Pasture Profit Index and the Irish Recommended List for Grass and Clover clearly shows that the best performing breeding programs for Ireland are those based in Ireland and the United Kingdom. It is likely that this trend will only become more obvious as a result of the development of the PPI given Ireland's huge dependence on grazed pasture. The grass varieties of choice in Ireland into the future will be those with excellent grazing traits. Future grass and clover breeding and evaluation in Ireland will be designed to satisfy the end demands of the grassland farmer.

Future direction and focus

The success of Irish grass based production systems is very dependent on six main challenges:

1. Continued adoption at farm level of improved grassland management practices and grassland technologies.
2. Focused research on grazing management to optimise herbage production, quality and utilisation, as well as the development of grassland management tools to facilitate improved grassland management practices.
3. Requirement to consistently achieve high clover proportions in grazing swards.
4. Ensure farm sustainability is improved and optimised with grassland as the main feed.
5. Continually inform national and international consumers of the associated health benefits of grass based milk and meat products.
6. Ensure that livestock farmers maintain efficient low cost predominantly grass based systems.

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Theme 1.
Resilient plants for grass based ruminant production systems, adapting grassland systems to the dynamics of climate and resource availability

Breeding resilient cultivars for European grass based ruminant production systems

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Abstract

This review addresses key factors and impediments that govern the efficient transfer of nutrient energy from primary producing grassland to ruminant milk and meat. Resilience is defined as the 'sustained production of high yield and quality herbage in a predictable, reliable manner to mirror the nutritional needs of grazing livestock across a full season'. The review focuses on permanent improved grasslands, defined as 'swards maintained at a high production potential by grass to grass renewal', frequently of 5 - 10 year longevity. Temporary summer grasslands, swards within cropping rotations or permanent unimproved pastures are not considered. Breeding progress to date is examined as are the primary objectives for the next generation of cultivars. This involves aligning grass productivity to ruminant demand in three primary aspects, intake potential, nutritional value and productivity profile. The opportunity to selectively improve plant traits affecting sward structure, chemical composition, seasonality and ability to persistent and perform under farm conditions is evaluated. The EU context involves appraising the impact of variables such as grass species and cultivar, regional abiotic stresses (water, temperature, nutrients, soil type, etc.), biotic stresses from disease and pests, regional diversity in sward management strategies and the opportunity to minimise the environmental footprint of ruminant farming.

Keywords: forage grasses, breeding, resilience, cultivar

Introduction

This short review paper is not intended to provide a comprehensive overview of contemporary grass agronomy and genetics knowledge, or to critique grass breeding strategies, particularly for improving climate, disease and pest resistance. Such bodies of work already exist (e.g. Conaghan and Casler, 2011; Kole, 2013a,b). Rather, it focuses on current and future breeding challenges for improving the efficiency of nutrient energy transfer from primary producing grass cultivars to ruminant milk and meat production. To examine for 'resilience' in this context requires a clear definition of the concept. Resilience Theory, as defined in human psychology by Greene *et al.* (2004) has been further contextualised as an individual's ability to successfully adapt to life tasks in the face of disadvantage or highly adverse conditions (Malgorzata, 2016). To make this concept applicable to grass breeding for resilience, the multifactorial parameters of Southwick *et al.* (2014), for assessing resilience in humans, requires only minor redefinition as shown in the following brackets: Understanding resilience requires the examination of variables in genetics, epigenetics, development, demographics (rural community), cultural (regional practices), economic and social (farm business) factors. The only extra aspect relevant to grasslands is to include the environment (climatic and edaphic). Given this multifactorial nature and for the purpose of this paper, the following simplified definition of resilience in grasses has been derived: 'proficient and sustained delivery of highly utilisable, high yielding herbage'.

Although greatly simplified, the implications are both complex and of critical importance.

- 'Proficient' introduces multiple production factors such as efficient use of input resources, including soil nutrients, light capture and, in some regions, water, plus an adaptability to optimise under

varying farm management practices (grazed, conserved, set stocked, rotational, zero grazed, intensive, extensive, etc.) and regional growing conditions. Proficiency also implicates the need to reduce the leakage of these inputs and so contribute to a lower environmental footprint and improved production costs of the farm business.
- 'Sustained' reflects the need for greater predictability and reliability across a growing season, over years and throughout as wide a regional climatic and edaphic range as possible. This aspect also involves the less predictable but unavoidable implications of climatic change with associated repercussions of changing disease and pest pressures.
- 'Utilisable' encompasses possibly the greatest weakness of all in ruminant production from grassland, namely the poor conversion rates of herbage mass and particularly the protein components into ruminant product. This feed quality and rumen function aspect has major implications for the environmental impact of grass based systems, with particularly critical issues associated with phosphate and nitrogenous compounds (ammonia, methane, nitrous oxide) lost to air and ground waters. This is attracting increased political and regulatory attention within the EU and globally. Also included within the utilisable concept is a need to better harmonise grass productivity profiles and 'grazability' across a growing season with livestock demands.

A further contribution to the resilience of swards can undoubtedly be introduced by sowing mixtures of grass cultivars and species, and additionally with a companion legume such as white clover (*Trifolium repens* L.). There is evidence that using mixtures to establish a wider sward genetic diversity can enhance resilience by lowering the magnitude of yield fluctuations across a season and between years / regions (Gilliland *et al*., 2010). Past mixture research has shown both yield enhancements over monocultures (England, 1968) or yields being intermediary to the component cultivars (Culleton *et al*., 1986; McBratney, 1978), but often the objective is to combine cultivars with specific key trait strengths to achieve a greater combination of disease resistance, winter-hardiness, drought tolerance, greater treading or tracking endurance, than is attainable within a single cultivar. Nonetheless, as this is not implicated in creating resilience within cultivars, it is outside the scope of this paper.

Breeders apply various selection techniques to enhance resistance to a specific stress factor, such as a foliar disease or climatic tolerance (Kole, 2013a,b) or employ novel strategies such as endophyte inoculation to implant pest resistance (Easton, 2007). Unquestionably, resistance to a specific factor can be essential to make a cultivar usable in a certain region. This is not, however, resilience breeding as defined above, as it is not multifactorial. So a specific resistance is only one among multiple factors contributing to greater cultivar resilience, the contribution of which varies regionally depending on the incident pressure.

Resilience breeding – production drivers

Traditionally, the most important breeding traits have been associated with high forage production, persistence and disease resistance (Smit *et al*., 2005; Parsons, *et al*., 2011) and differ little from those written over 45 years ago (Cooper and Breeze, 1971). There is evidence from north-western Europe that breeders have successfully raised the productivity of grasses over this time by around + 0.4 - 0.6% per annum depending on the yield component and region (Humphreys, 1999; Wilkins and Humphreys, 2003; Sampoux *et al*., 2011; McDonagh *et al*., 2016), with similar gains reported in New Zealand (Easton *et al*., 2002). Much higher production gains have been achieved in arable crops but this has largely been achieved by repartitioning to gain around + 1.0% per annum in cereals (FAOSTAT, 2015) or by introducing novel breeding strategies, such as in F1 hybrids to gain around 2.6% per annum in maize (*Zea mays* L.; Tollenaar, 1989). Apart from some specific examples, such as introgression of *Festuca* drought resistance genes into *Lolium* (Humphreys and Thomas, 1993) or exploratory studies into creating F1 hybrid ryegrasses using cytoplasmic male sterility (Deutsche Saatveredelung AG & Norddeutsche Pflanzenzucht Hans-Georg Lembke KG; personal communication), such innovative strategies have not been financially or functionally suited to large scale / routine breeding. So, genetic gain has required progressive increases in total shoot production, making grass yield gains arguably at least as good a breeding achievement as in arable crops. This alone does not represent a resilience improvement as this must include the qualitative factors driving greater proficiency, sustainability and utilisation of the herbage production profile. In this context, relatively modest genetic gains have also been made in digestibility, at around 0.5 - 1.0 g kg^{-1} DM per annum (Wilkins and Humphreys, 2003; McDonagh *et al*., 2016) but it is an area where greater breeding emphasis is now required to satisfy leading grassland farmers' requirements.

Resilience breeding – animal nutrition drivers

In a recent review of grassland productivity in Northern Ireland, Bailey *et al*. (2017) calculated that the average utilised yield on-farm was 5.0 t DM ha^{-1} yr^{-1} (dairy 7.5 t DM ha^{-1} yr^{-1}; beef & sheep 4.1 t DM ha^{-1} yr^{-1}) and utilisation of total grass grown was down to around 50% with negative implications for soil health and nutrient use efficiency from grassland (Anon, 2016). In Ireland, average grass utilised on dairy farms in 2015 was 7.8 t DM ha^{-1} (Hanrahan *et al*., 2018). In contrast, the Northern Ireland GrassCheck monitoring service (www.agrisearch.org/grasscheck), has recorded on-farm yields of 14-16 t DM ha^{-1} yr^{-1} with utilisation approaching 80% on the top 1% of best managed farms. However, as detailed elsewhere, the efficiency of use of ingested herbage energy and protein is disconcertingly low at around only 30% of total intake. Therefore, the key biological limit to livestock performance from grass is not a grass production ceiling but animal intake and metabolisation. While this dynamic undoubtedly has evolutionary roots as ruminants evolved to only achieve maintenance, plus one calving annually from natural grassland, commercial targets seek to produce 5,000 L of milk from forage and beef live weight gains in the region of 500 kg ha^{-1} yr^{-1}. This requires breeding advances in the intake and nutritional traits of new cultivars to achieve an on-farm target of 80% utilisation.

Wilkins and Humphreys (2003), concluded that the traits which impact on nutritive value include crude protein (CP) concentration, water soluble carbohydrates (WSC), neutral detergent fibre (NDF) and organic matter digestibility (OMD). Selection for high WSC has been shown to improve crude protein metabolism of grazed grass (Miller *et al*., 2001) and silage (Merry *et al*., 2006), and to reduce nitrogen (N) excreted in the urine.

Resilience breeding – animal intake drivers

The other pillar of utilisation is physical intake by grazing animals. Smit *et al*. (2005a) have shown significant differences between six perennial ryegrass (*Lolium perenne* L.) cultivars for sward surface height (SSH), bulk density (BD), proportion of green leaf (PGF), tiller density (TD), tiller weight (TW), length of sheath (LS), but not extended tiller height (ETH) or length of leaf blade (LLB). They further reported (Smit *et al*., 2005b) that herbage intake was significantly associated with SSH and PGF. As this was only observed in one of two experimental years, inconsistency might limit the on-farm benefits from breeding advances in these intake characters. In contrast, a number of experiments have shown that the greater the free leaf lamina (FLL) (Cashman, *et al*., 2014; Wims *et al*., 2013) and / or sward leaf content (Beecher *et al.,* 2015; Flores-Lesama *et al*., 2006; Gowen *et al*., 2003) the greater the animal performance. For example, Cashman *et al*. (2014) and Wims *et al*. (2013) found an average difference of 1.6 kg milk cow^{-1} day^{-1} between grazed perennial ryegrass cultivars with the highest and lowest FLL content. Furthermore, McDonagh *et al*. (2017) showed that FLL length is a good indicator of grass utilisation because as it increases, the pseudo-stem and true-stem contents decline, sward digestibility rises and post-grazing sward heights reduce. These authors also found a strong relationship between pre-grazing FLL length measured through the growing season in grazed swards and flag-leaf length (fll) in spaced plants. In addition, Sampoux *et al*. (2011), when comparing seven natural perennial ryegrass populations and 21 cultivars from the last 40 years, found a clear association of leaf and lamina lengths with spring and summer DM yields. Their data showed a possible negative impact of long leaves on sward persistency, but concluded that breeding for longer leaves and a high leaf elongation rate would improve the interception efficiency of incident radiation during re-growth which they expect would most significantly increase spring yields.

Tubritt *et al.* (2018) found significant differences in post-grazing or 'residual grazed' heights (RGH) of 3.7 to 4.8 cm between 30 perennial ryegrass cultivars when cattle grazed. Disappointingly, there was also a significant negative relationship between grazed yield and RGH as the lowest yielding cultivars had the lowest RGH and vice-versa. There was also clear evidence that this relationship was not obligated ($R^2 = 0.41$) as, for example, some cultivars with similarly good RGH values differed significantly by around 3 t DM ha^{-1} in grazed-off grass yield. While consistency over and within years still needs to be established, this evidence of cultivar diversity indicates a potential breeding trait to improve animal utilisation. Furthermore, if ongoing investigation confirms that secondary head development is reduced following lower RGH, this trait would also indicate enhanced herbage grazing quality on-farm, which is known to further enhance utilisation (O'Donovan and Delaby, 2005).

The magnitude of the benefit to grassland farming of improved grass quality and intake has recently been estimated from AFBI studies in Northern Ireland. Improving grass utilisation by 1t DM ha^{-1}, combined with improved grass quality, can potentially increase margin over feed costs by £204 – 334 ha^{-1} yr^{-1} on dairy farms or £160 – 218 ha^{-1} on beef farms (Anon, 2016). This dairy benefit was largely driven by reduced concentrate feed costs while the improved beef performance was due to a 21% ha^{-1} reduction in concentrates, an increase of 19% ha^{-1} in stocking rate and an improved live weight gain of 35% ha^{-1} from grass. Similarly, Teagasc figures show that a 1 t DM ha^{-1} increase in grass utilisation on dairy farms in Ireland is worth an additional €181 net profit ha^{-1} (Hanrahan *et al.*, 2018).

Resilience breeding – environmental impact drivers

There is increasing regulatory pressure on grassland farming to mitigate emissions of GHG, reduce nutrient losses to ground waters and to sequester carbon into soil sinks (ACRE, 2007). In the UK, 59% of total agricultural ammonia emissions come from ruminant farming (24%: beef, 31% dairy, 4% sheep; Misselbrook *et al.*, 2016) with agricultural livestock producing upwards of 9% of total anthropogenic GHG emissions as methane and nitrous oxide (Gill *et al.*, 2010). In a less urbanised / industrialised region such as Northern Ireland, ruminant emissions rise to over 70% of total emissions. In dairy cattle offered 35% concentrates and 65% fresh grass, livestock metabolism studies have shown that:

- of gross energy intake, 30% was lost in excretions, 6% as methane, 36% lost as heat, 23% retained in milk with 5% retained in the body (Hynes *et al.*, 2016a);
- of total protein fraction, tracked as total N, only 27 and 2% was retained in milk and body respectively, with 34% lost in faeces and 37% in urine (Hynes *et al.*, 2016b);
- of the phosphate ingested, only 33% was transferred to milk with 3.5% retained and the remaining 63.5% excreted, almost entirely within faeces (Ferris *et al.*, 2010).

A critical grass breeding challenge is, therefore, to decrease these losses by better transfer of the ingested herbage into animal product. The nutritive composition of the grass has a major role to play here with increased metabolisable energy content of herbage shown to improve conversion into animal product which, for example, can lower nitrous oxide (N_2O) emissions by reducing N excretion in the urine (Miller *et al.*, 2001b). Increasing herbage WSC content has also been implicated in reducing enteric methane eructation from ruminants (Martin *et al.*, 2010; Shibata and Terada, 2010). Here again there is opportunity for breeding intervention as there are many studies reporting cultivar differences in, for example, water soluble carbohydrate, crude protein, fatty acids, fibre digestibility, DM digestibility, (Downing and French, 2009; Gilliland *et al.*, 2002; Merry *et al.*, 2006; Miller *et al.*, 2001; Tas *et al.*, 2005; Wilkins *et al.*, 2000) with varying evidence of improved intake and animal outputs.

Resilience breeding – performance consistency drivers

If farmers are to place greater reliance on grass for their livestock nutrient supply then sustained resilience, as defined at the beginning of this paper, requires greater predictability and reliability across varying growing conditions. Talbot (1984), in assessing the sources of variation in grass cultivar trials located across the UK, concluded that years and locations imposed the biggest variances and were interchangeable. Therefore, cultivar testing protocols that involve multiple years, locations and retesting cycles, identify those that not only achieve higher overall performances but also have a greater resilience than those not approved.

On a macro 'EU-wide' scale, Table 1 shows the number of cultivars registered on the EU Common Catalogue of Varieties (www.ec.europa.eu/varieties, 2017) for the most important forage grass species compared to several major crop species. There are complex agri-economic factors underlying decisions on which country or countries a breeder will submit a new cultivar for registration and subsequent commercialisation, including testing costs, market volume and number of competing companies, as well as the inability to penetrate that market without a local independent recommendation. Furthermore, after making multiple national submissions to gain regionally approved performance data, breeders can reduce ongoing maintenance costs by only retaining one member state registration for EU market rights. So the data needs to be interpreted with considerable caution. Nonetheless, widely adapted cultivars are preferable from the agribusiness aspect as production costs are lower if fewer cultivars are produced in larger quantities. Given that the perennial grass species will not be re-sown annually as necessary for the arable crops, and which mostly have higher value and higher volume markets, there is no evidence from the numbers of registered cultivars that grasses are more climatically resilient than arable cultivars. This would suggest that forage grass cultivars are not more widely adapted across Europe than arable crops. The need for high rust (*Puccinia* spp) resistance in France or winterhardiness in Germany, which impose large differentials in the regional adaptation of grass cultivars, is a contributing factor, but no greater than among arable crops.

Table 1. Number of cultivars registered on the EU Common Catalogue 2017.

Forage grasses	**Perennial ryegrass 670***	**Italian ryegrass 248**	**Hybrid ryegrass 107**	
	Meadow fescue 103	Tall fescue 324	Cocksfoot 160	Festulolium 44
Arable crops	Barley 2-row 985	Barley 6-row 393	Wheat 2417	Durum 512
	Oats 358 (+39 naked)	Potato 1632	Sugar beet 1645	Linseed 182

* Estimated from total listing of 1093 amenity and forage cultivars.

Table 2. Comparison of recommendation consistency in the UK and Ireland 2010.

Total number of recommended perennial ryegrass cultivars		**120**
Proportion recommended by:	four testing authorities	10%
	three testing authorities	25%
	two testing authorities	22%
	one testing authority	43%

At a national level, Long *et al.* (2010) reported that of the 120 perennial ryegrass cultivars recommended in the UK and Ireland, only 10% were on all four recommended lists (England and Wales, Ireland, Northern Ireland, Scotland) and 43% of the cultivars were only approved in one region (Table 2).

This confirms observations from studies on cultivar ranking consistency. Wilkins (1989) and Wims *et al.* (2009) reported re-ranking under different growing conditions and concluded that this justified the need for regional recommended lists and explained regional variations in breeding gains reported by Wilkins and Humphreys (2003). This is understandable as a cultivar that is dormant enough to survive a northern British winter would be expected to have low spring yields in Co. Cork, Ireland, where the winter period is much shorter and prolonged frost is uncommon. Conversely, cultivars that perform well in Cork by not being winter dormant tend to suffer severe winter damage at northern sites. However, even in a relatively confined and benign maritime region such as Northern Ireland, substantial production variations can occur over relatively short distances. Table 3 shows the variation in yields and weather variances recorded across 30 dairy and beef farms in the six counties of Northern Ireland, during May 2017. All of these farms were operating to an optimum management level in what was not an extreme weather period and yet growth in Armagh and Down was 0.95 t DM ha^{-1} lower than the average of the other counties and 1.25 t DM ha^{-1} less than Antrim, due to lower rainfall and increased soil moisture deficits.

When weather patterns are more extreme, even larger fluctuations in yields occur. For example, the long term perennial ryegrass cultivar performance trial work at AFBI Crossnacreevy, Northern Ireland, shows ten year average yields for perennial ryegrass of 12.3 t DM $ha^{-1}yr^{-1}$ under a simulated grazing management and 16.4 t DM $ha^{-1}yr^{-1}$ under a conservation management, with an annual variation of ± 5.5t and ± 7.2t DM $ha^{-1}yr^{-1}$ respectively (Meehan, 2016). Such extremes can be unsustainable for farmers who have committed the bulk of their livestock performance to grass production. Hence, in 2002 and 2013, bad weather in Northern Ireland so severely depressed grass yields that Government had to provide a 'weather aid' and 'fodder crisis' support scheme for farmers, amounting to over £6.5 m. By the end of August 2013, the main silage growing period, yields were down by 25 - 30%. Of the silage that was made, average intake potential was down from 77 to 67%, ME was down from 11.0 to 10.1 MJ kg^{-1} DM and crude protein down from 13.6 to 10.4%, compared to the previous year, with the worst samples having only intake potentials at 51%, ME at 7.7 MJ kg^{-1} DM and crude protein at 6.1%. Even the average values equated to a reduction in milk yield potential from grass of -4.3 kg day^{-1} cow^{-1} (at 8 kg day^{-1} concentrate feed level) or a liveweight gain potential of -0.25 kg day^{-1}, compared to 2001. Challenges of this magnitude are currently beyond the capability of grass breeding to address either locally or EU wide. The only partial remedial measures are available through local monitoring services such as GrassCheck (www.agrisearch.org/grasscheck), which uses a growth prediction model to forecast expected grass yields two weeks in advance.

Table 3. Variation in weather and grass growth parameters between NI countries for the 2017 GrassCheck dairy farms (McConnell, personal communication).

Region (county)	**Total rainfall (mm)**	**Average daily temperature (°C)**	**Daily growth rate (kg DM ha^{-1})**	**Total yield (t DM ha^{-1})**
Antrim	49.9	12.0	101.9	3.16
Armagh	42.4	12.4	63.4	1.97
Down	35.3	11.9	60.3	1.87
Fermanagh	46.8	12.3	87.8	2.72
Londonderry	35.7	12.2	89.0	2.76
Tyrone	53.2	12.3	92.2	2.86
Average	43.9	12.2	82.4	2.56

Nonetheless, commercially successful cultivars should not significantly re-rank in their key characteristics within the scope of normal management practices and there is evidence to show this is the case. McDonagh *et al.* (2017) found that eight perennial ryegrass cultivars did not re-rank to any great extent in production, quality or persistence, despite different N application rates, defoliation frequencies and all with and without white clover inclusion. Similarly, Aldrich and Elliott (1974) found no re-ranking between cutting and grazing systems. So, breeding programmes have delivered some level of resilience to management variation in terms of relative cultivar performance, but not to more acute weather pattern variations.

Resilience breeding – current breeder priorities

Given the considerable challenges posed by the breeding drivers discussed above, questions arise as to what breeders are and can do to effectively address them. A 'straw poll' was conducted for this review, in which forage grass breeders across Europe were asked to score their selection priorities for a total of 33 traits, across five groupings, as either A (very important to essential), B (somewhat important / important) or C (useful / irrelevant):

- 8 productivity traits: total herbage production; spring herbage production; summer herbage production; autumn herbage production; 1st cut silage yield; 2nd cut silage yield; 3rd cut silage yield; overwinter / low temperature growth.
- 9 herbage quality: spring grass quality; summer grass quality; autumn grass quality; digestibility; crude protein content; water soluble carbohydrate (WSC) content; fibre content; fatty acid profile; tannin content.
- 4 structural parameters: lamina length; leaf area index; erect / prostrate habit; sward density.
- 7 resistance factors: rust resistance; mildew resistance; *Drechslera* resistance; other diseases, persistence / longevity; drought tolerance; cold tolerance / winter kill.
- 5 specialist characters: nitrogen use efficiency; phosphorus use efficiency; utilisation under grazing; livestock output measure; lower methane emissions.

For perennial ryegrass, only four traits were A-classed by all breeders (total and spring production, spring quality and digestibility), with a further six A-classed by a majority of breeders (1st cut silage yield, sward density, rust and *Drechslera* resistance, utilisation under grazing and persistence / longevity). Fatty acid profile and tannin content were C-classed as irrelevant by all breeders, but otherwise there was no clear consensus on the priorities of the remaining traits. Interestingly, one breeder had only a single 'essential trait' (total yield), while another breeder listed 23 of the 33 traits as A-class priority. Overall, productivity and resistance traits retained high priority with herbage quality and structure less so, despite their importance to animal productivity as already described (Table 4). Specialist characters were also given a high priority, though there was little consensus on the priorities between breeders. A number of 'additional' characters were reported by the breeders, each largely specific to an individual breeder. These

Table 4. Percentage of traits in each group assigned to one of three importance classes.

Trait group[1]	Perennial ryegrass			Hybrid ryegrass			Tall fescue			Cocksfoot			Timothy		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Productivity	55	30	14	50	50	0	38	38	25	38	50	13	38	38	25
Herbage quality	35	35	30	28	44	28	33	44	22	44	33	22	44	33	22
Structural parameters	32	46	21	25	38	38	25	75	0	25	75	0	25	75	0
Resistance factors	52	38	10	43	50	7	29	43	29	29	71	0	14	86	0
Specialist characters	54	11	34	30	30	40	0	60	40	0	60	40	0	60	40

[1] Classes: A = very important/essential; B = somewhat important/important; C = useful/irrelevant.

included fibre or cell wall digestibility, reheading, livestock wear, tillering, poaching / wear resistance and seed yield.

Survey results were also received for hybrid ryegrass (*Lolium hybridum*), tall fescue (*Festuca arundinacea*), cocksfoot (*Dactylis glomerata*) and Timothy (*Phleum pratense*). As summarised in Table 4, trait priorities for hybrid ryegrass were largely in line with those for perennial ryegrass except, as a short term grass, production characters were given greater weighting relative to the other traits. Compared to perennial ryegrass, in the other three species, yield was less of a dominant characteristic, herbage quality was of similar priority, structural parameters and resistance factors were no less than 'important' (except tall fescue resistance) and special characters were much less important. The most frequent additional character proposed by the breeders was seed yield.

These results reflect the challenge of breeding for genetic gain in a crop that does not have a singularity of end-use and with the ultimate product depending on the efficiency of the ruminant 'end-user'. When viewed as a totality, they give some indication of the challenge of achieving a multifactorial resilience by targeting progress across a wide diversity of traits.

All except one breeder reported that their germplasm resources were entirely either 'elite/improved' (existing commercial cultivars) or 'adapted' (of known favourable traits but not from existing cultivars). This other breeder was using between 1 - 5% of 'unadapted' germplasm (of high genetic diversity without trait assessment – e.g. wild populations) to breed both perennial and hybrid ryegrasses. So, virtually all of the breeding effort is seeking to achieve improvements from within the genepool of current cultivars and associated material. As of these forage grasses are allogamous, they require several maternal plants of sufficient diversity to overcome the self-incompatibility genes (Klaas, 2011) and ensure commercially viable seed production capability. This implants a greater phenotypic variance within grass cultivars compared to autogamous or clonal cereals and makes recurrent selection successful.

The best evidence of this comes from the statutory Plant Breeders Rights registration schemes in the UK. Table 5 shows the magnitude of differences between plants within registered cultivars for several characteristics measured on spaced plants in Distinctness, Uniformity and Stability tests of perennial ryegrass (data from AFBI Plant Testing Station, Crossnacreevy, Northern Ireland). These data are from registered cultivars, which are therefore 'uniform' and so, show that a difference in heading date between plants of 2.7 - 5.4 days can exist. Similarly, flag leaves can range between 3.6 - 6.1 cm in length and

Table 5. Magnitude of range within perennial ryegrass cultivars for spaced plant characters.

Character name	Flowering date	Spring angle	Spring height	Spring width	Spring shape
units	days	degrees[1]	cm	cm	cm^3
Maximum	5.4	12.4	11.7	11.3	0.28
Minimum	2.7	7.1	3.9	6.8	0.10
Average	3.8	9.8	8.6	9.1	0.18
Character name	**Tiller height[2]**	**Plant width[2]**	**Flag leaf length**	**Flag leaf width**	**Flag leaf area**
units	cm	cm	cm	mm	cm^2
Maximum	13.6	12.7	6.1	2.2	3.3
Minimum	9.0	7.7	3.6	1.2	1.7
Average	11.6	10.3	5.0	1.7	2.6

[1] Angle from ground level.

[2] At ear emergence.

1.2 - 2.2 cm in width, giving a leaf area range of 1.7 - 3.3 cm^2. The significance of this variation is that McDonagh *et al*. (2017) showed that differences in free leaf lamina, measured in swards, were a good indicator of intake by grazing cattle and that these differences correlated closely to spaced plant measured leaf length differences, both when swards were in the reproductive ($R^2 = 0.88$) and vegetative ($R^2 = 0.99$) phases. Given that the sward and spaced plant measurements came from distantly separated locations and different years, FLL / fll appears to be a trait that impacts on animal intake / utilisation and is amenable to selection in breeders' plant nurseries.

Therefore, there is variance within registered cultivars that can be exploited to improve some traits that are important for animal performance and justifies breeders focus on using elite maternal germplasm. However, to make progress on a multifactorial (resilience) basis may require more innovative approaches. It was notable that only one breeder reported using molecular selection methods in their current breeding programme, though several stated that they had future plans to do so. Genomic analysis can facilitate multivariate selection to address the multifactorial resilience requirement, though the grasses have lagged behind other crops in the use of these tools. This is partly due to allogamay, as it is harder to capture gene variants within cultivars that are effectively populations compared to autogamous or clonal crops. Cost has also been prohibitive in the past and although now becoming cheaper still represents a significant investment. Typical estimates for a moderate genomic programme for grasses include a €300,000 cost to develop the training population and €100,000 to annually verify and perform genotyping on progeny material, with any novel phenotyping costs being additional. This would be a bare minimum approach and yet may still be beyond the financial capacity of a grass breeding programme. So, the following three recent examples of genomics in grass breeding have all involved regularly pumping prime investment from public or academic funders.

- The forage grass breeding programme of the Institute of Biological, Environmental and Rural Sciences in Wales (www.aber.ac.uk/en/ibers*)*, exploits its academic links within the University of Aberystwyth to conduct 'public good' breeding and attract funding from Government (Defra, http://tinyurl.com/klvcdo7) and research funders such as BBSRC (www.bbsrc.ac.uk), the Technology Strategy Board (http://tinyurl.com/y7sq6c44) and a seed industry company.
- Teagasc, Oakpark, Ireland report development costs for their molecular grass breeding programme at around €500 - 600,000 annum $^{-1}$, for a medium sized genomics screening capability, which has required Government (DAFM) funding (www.teagasc.ie).
- DLF in Denmark linked with Aarhus University (www.au.dk/en) for a genomics programme in 2011 and after five years had examined around 1,800 ryegrass families, all with phenotypic data and had identified 1.8 million DNA markers (approximately 1% of the 2.7 Gb ryegrass diploid genome). The work has been further supported through a 'public good' methane emissions study, partnered with Tystoftefonden (www.tystofte.dk) and funded under the Green Development and Demonstration Program, Ministry of Environment and Food, Denmark (www.mst.dk/service/om-miljoestyrelsen).

Other grass breeders, such as DSV target specific traits, seeking causal genes for characters in quality traits (e.g. lignin synthesis) and plant structure (e.g. lamina length). There is a growing body of scientific evidence and experience in cytogenetics, genotyping, next generation sequencing and bioinformatics to support further progress in this area. Evidence of synteny across genera in the Gramineae (or Poaceae), such as Brachypodium, rice (*Oryza sativa*), sorghum (*Sorghum bicolor*) and more recently the barley (*Hordeum vulgare*) genome (Mayer *et al*., 2011), novel approaches such as TILLING (Manzanares *et al.*, 2016), or categorisation of specific quantitative trait loci for e.g. leaf length in ryegrass (Barre, 2009) and improved cell-wall degradability (Barrière *et al*., 2003; Bolwell, 2000) are opening new opportunities.

Therefore, these examples indicate a new phase of opportunity to breed for greater resilience and to expect breeding progress on a multifactor is no longer such an unattainable goal. However, the financial limits within grass breeding business models mean that companies currently can't entirely self-fund genomic breeding.

Resilience breeding – cultivar evaluation drivers

For many years, official evaluation schemes across Europe sought evidence of improvement in individual traits, the most important of which were DM yield and persistency, with resistance to any acute regional disease/climatic factor being a baseline requirement. Latterly, digestibility was introduced, but improvement continued to be required on a trait by trait basis, with 'overall performance' only used for marginal pass/fail decisions. It was accepted that these traits were detached from the animal product as animal based trialling demands resources beyond what most testing authorities can provide or breeders afford to fund. Hence, small plot field trials are expected to continue for large scale cultivar evaluations to reduce candidate numbers to a smaller number of new elite performing cultivars (Conaghan *et al.*, 2008). However, given the body of evidence presented above, showing the need for progress in characteristics that are now known to impact on animal intake, nutrition and environmental footprint, a more multifactorial approach to cultivar evaluation is clearly required. There are already a number of evaluation schemes that use indices to provide an overall performance indicator for perennial ryegrasses.

The French small plot evaluation scheme (Reglement technique d'examen des varietes de plantes fourrageres et a gazon; www.gnis.fr/reglementation-semences), applies an index rating to cultivars after they have passed the baseline evaluation criteria. Coefficients are applied to the yields (1 - 100% on measured values and 1 - 9 for notes) for a range of characteristics (total and seasonal yields, reheading, resistance to diseases, operational flexibility, flexibility of the foliage, persistence / sustainability and nutritional value – total N composition / ADF content / soluble sugar content), to give an overall rating. This allows for inferiority in some characters to be offset by favourable expression in others, but with an elimination threshold set for characters of major agronomic importance, such as reheading and rust resistance.

Similarly, the Dutch Plantum index for grasses (Protocol Beslissingen Opname en Afvoer Engels Raai Voeder 2017 Commissie Samenstelling Aanbevelende Rassenlijst (http://tinyurl.com/y6u4hbor) assigns weighting and scale factors to total yield, first cut silage yield, crown rust and ground cover, with minimum standards for winterhardiness and all but the first cut yield.

These indices attempt to represent the overall value of a cultivar for animal production, based on the small plot characters, as listed. An alternative approach is to form indices based on the calculated financial value to the farm business of the herbage produced. So DairyNZ use a Forage Value Index (http://tinyurl.com/y6vbacb6) in New Zealand. This is calculated from the economic value of the seasonal yields on a regional basis and each cultivar's DM production level for each seasonal period. Cultivars are given a star rating to indicate an estimated annual value to the farm of - \$78 to + \$29 (1 star) up to + \$351 to + \$458 (5 star), using an on-line selection tool. In Ireland, Teagasc have developed a Pasture Profit Index (PPI; www.teagasc.ie/crops/grassland/pasture-profit-index) that provides predicted economic values for cultivars that have been recommended by the Government (DAFM). This research based index (McEvoy *et al.*, 2011; O'Donovan *et al.*, 2016), assigns a financial value to each cultivar based on the seasonal (spring, summer, autumn) and total yield, persistency and digestibility of the herbage produced in small plot trials. In both of these financial based indices, there has been a very strong engagement of farmers and an invigorated interest in grass cultivars, more production from grass and in reseeding with better cultivars.

Teagasc have now implemented a further level of farmer involvement by establishing a network of 66 farms to evaluate 11 currently recommended cultivars, sown in monoculture under intensive grazing systems (Byrne *et al.*, 2017). The farmer monitors herbage production through weekly paddock cover estimations

(O'Donovan *et al*., 2002) and uploads data into PastureBase Ireland (PBI), a farmer decision support tool and database (Hanrahan *et al*., 2017). Sward quality and ground score are measured by trained technicians at fixed periods during the season. In 2017, there was a range of 1.9 t DM ha^{-1} in total annual DM production, 44 g kg^{-1} DM for DMD and 0.7 for ground score. There are a number of implications of this scheme. It requires a large number of farmers who will commit and adhere to the evaluation scheme and incurs greater variances as not all cultivars are on all farms, sown in the same year and must account for regional conditions and farmer practice differences. It also cannot be conducted until after the initial small plot scheme has identified the few elite cultivars from among the many candidates. It does, however, produce performance data under actual farm grazing, across the actual range of farming conditions and greatly enthuses the 'co-research' farmers (and their neighbours). The final phase in this PPI / PBI initiative is to adopt characters as described in earlier sections that enhance animal intake and utilisation and reduce nutrient losses to the environment, so that the indices and evaluations comprise a multifactorial calculation of key animal performance drivers.

An unexpected implication has been that some of these co-research farmers are moving away from using mixtures to sowing single cultivars. As they have gained experience of using single cultivar swards and identified specific ones on which their livestock has optimised, they have sought to expand the area available to graze. Without this precision management experience, the loss in flexibility gained from mixtures may be detrimental to less grass-skilled farmers. If this became common practice, there would also be considerable problems for breeders and seed producers meeting the needs of a cultivar demanding market that could change rapidly. However the 'milchindex' trademark has been successfully used by DSV to market cultivars of high digestibility and quality in Germany as a premium brand in an otherwise price sensitive market. This typifies the potential benefits that breeders might gain if grass cultivars were more specifically defined for their animal performance potential to farmers.

Concluding remarks

It is widely accepted that improved efficiency of animal production from grass is the ultimate goal of forage grass breeding for European temperate regions (Wilkins and Humphreys, 2003) and identifying cultivar characteristics that can be highly utilised and influence animal performance is important from all aspects of grassland (Wims *et al*., 2013). Grass breeders must, as always, seek to be at the forefront of such grassland improvement. Today, this is increasingly driven by the twin need to fulfil leading grassland farmers' requirements for quantifiable animal performance at grass and the regulatory imperatives to reduce GHG loses to the atmosphere and nutrients to ground waters. As overviewed in this paper, there is ample research evidence of grass characteristics that will enhance animal intake, metabolic utilisation and so production from home-grown grazed and conserved grass. These traits will equally help lower the environmental impact of ruminant farming. It is also clear, however, that in assessing the evidence for such 'animal-performance' characters there are often qualifications needed regarding repeatability, accuracy, magnitude of the value, interaction with and independence from other characters, as eluded to. Notably, the evidence from Smit *et al.* (2005b) of inconsistent animal performance responses to expressed differences in grass structural traits indicates that it will be incumbent on farmers to manage their swards with sufficient precision to fully gain from any such breeding advances. Leading grassland farmers are, however, already operating at this level of expertise. Therefore, none of this should be an impediment to grass evaluators now actively adopting novel characteristics, particularly as the use of indices provides scope to account for any uncertainties, while still delivering a multifactorial assessment of the animal value of new cultivars. With these in place, breeders will be able to target improvement in multiple traits, which the straw poll indicated is within their current capability either by conventional methods or through their ambitions around genomic selection. There is however, some evidence that developing cultivars with high animal-value characters could lead to more use of single cultivar swards with implications for the business models of breeding companies and seed producers.

Taking the available evidence overall, it is clear that to improve animal performance at grass through a strategy of resilience breeding does not require the discovery of further new traits or sources of new levels of diversity than currently available among commercial breeding stocks. If cultivars are bred and rewarded in evaluation tests for achieving greater resilience, defined as a 'multifactorial' estimation of animal performance potential (with regional climate / disease resistance and management practice needs met), this will be highly valued by leading farmers and environmental regulators. The benefit to breeders is that once grass cultivars are individually recognised for their financial contribution to farm efficiency and profitability, the opportunity to broker a seed price that better reflects their true value and cost of development becomes an attainable goal. Most importantly, this should provide a greater financial resource to invest in further breeding advances.

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Influence of pasture-feeding on milk and meat product quality

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Abstract

The majority of cows worldwide are fed indoors on a diet of mixed ration, while in areas with temperate climates, such as Ireland and New Zealand, the feeding regime of dairy and beef herds is almost entirely pasture-based. Animal feeding regimes and herd management practices are linked to differences in organoleptic and nutritional quality attributes of milk, dairy and meat/beef products, with pasture-based feeding systems being associated with superior quality produce. Consumers generally perceive that milk and meat products produced from outdoor grazing pastures are 'healthier' than produce derived from indoor feeding systems, based on animals fed typical indoor rations and concentrates. However, while research has demonstrated differences in milk and beef quality based on different feeding systems, data are limited on the impact of dairy and beef products produced from different feeding systems on human health. In this review, we compare the nutritional quality of bovine milk, dairy and beef produce from pasture feeding with indoor feeding systems and summarise the current data with regard to health impacts of dairy and beef from different feeding systems, highlighting specific bioactive compounds found naturally in these products as a result of feeding regime.

Keywords: milk, beef, nutritional quality, pasture-fed

Introduction

The composition of bovine milk and meat, in particular the fatty acid composition, can be significantly influenced by the feeding regime. In many regions of the world including the United States, the Middle East, Asia and parts of Europe, cows and cattle are fed indoors and receive a diet of grass/maize silages supplemented with concentrates, known as total mixed ration (TMR). However, in Ireland and New Zealand, they are typically fed outdoors where they have access to fresh pasture, which is why there is a predominant seasonal calving regime and milk production system in Ireland. Pasture-based dairy and beef products are popular amongst consumers as they are positively associated by consumers with good animal welfare and more natural and healthier products (Verkerk, 2003). Specific feeding regimes and herd management practices such as pasture feeding are linked to superior organoleptic and nutritional quality attributes of milk, dairy and meat products (Haug *et al.*, 2007; Mann *et al.*, 2003).

Nutritional quality of milk

Milk and dairy products derived from it are among the most nutritious foods available for human nutrition, being excellent sources of high quality protein and important sources of many minerals, notably dietary calcium, magnesium and phosphorous, vitamins and bioactive compounds. Bovine milk composition varies in response to animal nutrition and stage of lactation, but is generally composed of 5% lactose, 4% lipid, 3.2% protein and 0.7% mineral salts (Severin and Wenshui, 2005).

Bovine milk is an important source of dietary protein as it provides a source of essential amino acids. The major proteins in milk include whey proteins (6.3 g l^{-1}) and caseins (26 g l^{-1}) (Severin and Wenshui, 2005). A scoring system to describe dietary protein quality was proposed by the Food and Agricultural Organisation (FAO) of the United Nations in 2013, called the digestible indispensable amino acid score (DIAAS) (FAO, 2013) and dairy proteins have one of the highest DIAASs (Wolfe, 2015). Furthermore, milk proteins contain latent bioactive peptides encrypted within their amino acid sequences which are released upon proteolysis such as occurs in the gastrointestinal tract. These bioactive peptides exhibit a range of biological activities including antihypertensive, antithrombotic, cytomodulatory, immunomodulatory and antimicrobial activity, as examples (Mills *et al*., 2011). The mineral composition of milk is dependent on animal nutrition, stage of lactation and genetic factors (Zamberlin, 2012). Mineral elements in milk and dairy products exist as inorganic ions and salts and as part of organic molecules including proteins, fats and carbohydrates. While milk is a source of all the essential minerals for human nutrition (Cashman, 2006), the most abundant minerals present in bovine milk are calcium and phosphorous, mostly associated with the casein micelle structure, and it is also a good source of magnesium and potassium. Animal diet does not significantly influence the content of these minerals in milk. Milk is a good source of some vitamins, notably the fat soluble vitamin A and E (found in the milkfat fraction), which are influenced by animal diet, with high levels reported in fresh grass. It was reported that milk produced in summer months in Finland was three – four times higher in vitamin E than that produced in winter, as a result of feeding regime (Syvaoja *et al*., 1985). Milk is also a source of some water soluble vitamins especially riboflavin, thiamin and vitamin B12, which are derived from a combination of animal diet and the rumen microbiota and vary with the stage of lactation. It was reported that vitamin B12 concentration was six times higher in colostrum than in milk produced 39 days after calving, while folate concentration was nine times higher in colostrum (Duplessis *et al*., 2016).

More than 50% of the fatty acids in bovine milk are derived from the diet (Lindmark Månsson, 2008) and over 50% of milk fatty acid content is composed of saturated fatty acids (SFA). While these fatty acids have received negative attention in terms of human health, more recent research suggests that the association between SFA intake and heart disease risk factors requires re-evaluation. Indeed, a meta-analysis of prospective epidemiologic studies evaluating the association between SFA intake and cardiovascular disease (CVD) in 2010 revealed there was no significant evidence to conclude that dietary SFA was associated with increased risk of coronary heart disease (CHD) or CVD (Siri-Tarino *et al.,* 2010). In 2015, a meta-analysis of 22 studies revealed an inverse association between dairy consumption and overall risk of CVD and stroke (Qin *et al*., 2015). Several of the SFA found in milk have been shown to exhibit beneficial activities; butryic acid (C4:0) accounts for approximately 10% of all fatty acids in bovine milk (Jensen, 2002) and has been associated with anti-cancer properties (German, 1999), and lauric acid (C12:0) and capric acid (C10:0) were revealed to have antimicrobial properties (Petrone *et al*., 1998; Sprong *et al*., 2001; Sprong *et al*., 2002). The long chain SFA found in milk, stearic acid (C18:0) does not appear to raise serum cholesterol levels (Grundy, 1994). Bovine milk is also a source of monounsaturated fatty acids (MUFAs) and polyunsaturated fatty acids (PUFAs). The essential PUFAs, omega 3 (α-linolenic acid, 18:3n-3) and omega-6 (linoleic acid, 18:2n-6), which cannot be synthesised by humans and must be acquired from the diet, occur in milk at levels between 0.5 - 2.0 and 1 - 3 wt%, respectively (Jensen, 2002). As well as exhibiting numerous beneficial effects *in vitro* and *in vivo* (Connor, 2000; Siddiqi *et al*., 2008; Dupertuis *et al*., 2007; Poulsen *et al*., 2007), these fatty acids are converted to eicosanoids which play essential metabolic roles in the body. The Western diet has been associated with an increase in the intake of n-6 fatty acids resulting in a dietary n-3 to n-6 fatty acid ratio of between 1:10 and 1:20 which is well above the desirable ratio of 1:1-4 (Molendi-Coste *et al.,* 2011). However, the ratio of n-3 to n-6 fatty acids in milk is favourable compared to most other non-marine foods (Haug *et al*., 2007) and can be influenced via feeding regime, as discussed later. The bioactive conjugated linoleic acid (CLA) has been associated with numerous beneficial effects and has been shown to provide protection against cancer, diabetes, obesity and CVD based on *in vitro* and *in vivo* studies in animals (Yang *et al.,* 2017). Bovine milk is a source of CLA, particularly the cis-9, trans-11 isomer (c9t11 CLA), which accounts for over 90% of total milk fat CLA (Stanton *et al*., 2003). It is produced as an intermediate product in the biohydrogenation of unsaturated fatty acids in the rumen, when dietary linoleic acid is converted to stearic acid by bacteria in the rumen and it can also be produced in the mammary gland from vaccenic acid (C18:1, t-11) by the action of the enzyme delta9-desaturase (Kepler *et al*., 1966).

The fat in milk occurs as milk fat globules are surrounded by the milk fat globule membrane (MFGM) which is composed primarily of cholesterol, phosphatidylcholine, glycolipids, glycoproteins, sphingomyelin and gangliosides (Ward *et al*., 2006). The MFGM is recognised for its antimicrobial activity (Douëllou *et al*., 2017; Sanchez-Juanes *et al.,* 2009) and has been associated with numerous health benefits (Spitzberg, 2005; Mills *et al*., 2011). Most recently, a randomised clinical trial in humans revealed that milk fat delivered within an encapsulated MFGM structure does not impair the lipoprotein profile of humans in contrast to milk fat without a MFGM (Rosqvist *et al*., 2015). Lactose, the major milk sugar and its derivatives, have received increasing attention in light of their prebiotic activities (Schaafsma, 2008). In this regard, it has been suggested that lactose be redefined as a 'conditional prebiotic' (Szilagyi, 2004).

Milk and dairy product quality from pasture-based feeding system

Milk and dairy produce from pasture differ from that produced from TMR diets fed indoors. This was recently reported in a series of publications by Teagasc researchers as part of an ongoing research programme addressing the potential benefits of dairy produce from pasture-based systems compared to TMR systems. This work has already clearly shown benefits in terms of superior nutritional properties, appearance, colour and flavour of milk and dairy products including butter and cheese from pasture-fed dairy cattle (O'Callaghan *et al*., 2016a,b, 2017). O'Callaghan *et al*. (2016 a) investigated the impact of different feeding systems on milk composition and quality over an entire lactation. Feeding a perennial ryegrass pasture or a perennial ryegrass/white clover pasture resulted in milk with significantly higher concentrations of fat, protein, true protein, casein and whey compared to milk from cows fed TMR indoors. Moreover, milk of pasture-fed animals was two-fold higher in the c9t11 CLA content of milk, which as mentioned above has been associated with numerous beneficial health effects. In addition, pasture-feeding resulted in milk with significantly increased n-3 PUFAs, significantly decreased n-6 PUFAs and, therefore, an improved n-3 / n-6 ratio compared to TMR-based milk. The TMR-derived milk had a significantly higher thrombogenic index compared to the pasture-derived milk. Thrombogenic index is an indicator of the tendency for clots to be formed in the blood vessels and a higher index is therefore undesirable.

Butter manufactured from milk produced on the perennial ryegrass pasture, perennial ryegrass / white clover pasture and TMR were significantly different in terms of quality characteristics, nutritional properties and consumer perception (O'Callaghan *et al.,* 2016b). Butter produced from pasture-fed cows was superior in appearance, flavour and colour as confirmed by sensory panel data. Unsurprisingly, the pasture-derived butters revealed improved nutritional properties including lower thrombogenicity scores, higher c9t11 CLA and β-carotene concentrations. β-carotene is a precursor of vitamin A and carotenoids such as β-carotene exert several biological functions including antioxidant activities, tumour inhibition and induction of apoptosis (Milani *et al.,* 2017). Feeding system also influenced the nutritional properties of full-fat Cheddar cheese (O'Callaghan *et al*., 2017). Pasture-derived cheese was yellower in colour than its TMR-derived counterpart which was positively correlated with increased β-carotene content. Again, significantly lower thrombogenicity scores were reported for the pasture-derived cheese as well as 2-fold higher levels of c9t11 CLA isomer and vaccenic acid, which is a precursor of CLA. The pasture-derived cheeses had significantly higher n-3 fatty acid contents whereas the TMR-derived cheeses had significantly higher n-6 fatty acid content.

Feeding system can significantly impact the technological properties of milk and dairy products, as has being well recognised in relation to the spreadability of butter (Banks and Christie, 1990; Wood *et al*., 1975; Couvreur *et al*., 2006; Hutraud *et al*., 2007). We recently also reported similar findings in that significant differences were observed in the textural and thermal properties of butters manufactured from pasture-derived and TMR-derived milks as a consequence of differences in fatty acid concentrations (O'Callaghan *et al.,* 2016 b). Significantly higher hardness scores at room temperature were reported for the TMR-derived butter compared to the pasture-derived butters which were attributed to the higher SFA content (which approached significance) and the significantly higher concentrations of palmitic acid in the TMR-derived butter. Onset of crystallisation for TMR butters also occurred at significantly higher temperatures, a factor which would contribute to increased hardness at room temperature. Volatile analysis revealed significant differences between butters and toluene was higher in pasture-based products and identified as a differentiating flavour compound. In terms of sensory analysis, the butter manufactured from grass-derived milk scored highest in terms of appearance, flavour and colour. Similarly, the TMR-derived cheese exhibited increased hardness compared to the pasture-derived cheeses at room temperature which was attributed to the significantly higher concentration of palmitic acid in the TMR milk.

The results indicate that pasture-based milk contains significantly higher concentrations of fat, protein and casein than milk produced from cows fed TMR diets indoors, and in particular, milk from pasture-fed cows (grass with or without white clover) has significantly higher concentrations of healthy fatty acids. Such data provide scientific substantiation for dairy produce from pasture-fed animals as superior, from a compositional and nutritional perspective, to those derived from their indoor counterparts. However, the long-term benefits of pasture-based produce on human health remains to be confirmed through human clinical studies.

Variation within pasture-based systems

Seasonal variation in grass growth has been shown to significantly influence the fatty acid composition of milk (Parodi, 1977; Riel, 1963; Stanton *et al.*, 1997). For example, the CLA content of milk fat has been reported to range from ~2 to 30 mg g^{-1} fat (Riel, 1963; Stanton *et al.*, 1997), with much of the variation being attributed to seasonal influences on pasture quality. High CLA contents were reported in milk from cows fed on pasture in spring (April and May, ~6.8 mg CLA/g fat) and low levels were reported in mid summer and winter (~4.3 mg CLA g^{-1} fat) (Kim *et al.*, 2009). There are seasonal variations in the n-3 content of milk with higher levels reported in summer and lower in winter. A recent meta-analysis of organic compared with conventional milk reports higher n-3 PUFA and CLA in organic milk and these milk composition parameters showed strong positive associations with grazing intake. In contrast, there were positive associations between concentrate, maize silage, hay and straw intake and SFA content (Średnicka-Tober *et al.*, 2016). Cullinane *et al.* (1984) showed a seasonal variation in the fatty acid composition of Irish butter including variations in the levels of butyric acid and C18-unsaturated fatty acids.

Impact of different feeding systems on human health: milk

Studies investigating the differential effects of milk products produced from different diets and management systems on human health are scarce and those which have been conducted have generated mixed results. In a randomised controlled study, Werner *et al.* (2013) investigated the impact of consuming butter derived from mountain pasture-grazing cows compared to consumption of conventional Danish butter on risk markers of metabolic syndrome in a 12 week study involving 68 healthy subjects. As there were no differences in blood lipids and inflammation between groups at the end of the study, the authors concluded that mountain pasture-derived dairy products were not healthier than those derived from high input conventional systems despite the fact that cholesterol-raising SFAs were reduced by 20% in the butter derived from pasture-fed cows. Consumption of butter naturally enriched with ruminant trans fatty acids, of which vaccenic acid was the predominent isomer and equivalent to ~1% of daily energy, did not significantly impact low-density lipoprotein (LDL) cholesterol levels in 61 healthy women following a four week study (Lacroix *et al*., 2012). The butter naturally enriched with vaccenic acid was produced from selected cows fed concentrates, alfalfa and corn silage, with the addition of corn oil. In contrast, consumption of butter with a naturally higher content of vaccenic acid and MUFAs did significantly reduce total high-density lipoprotein (HDL) cholesterol in healthy young men in a double-blind, randomised five week parallel intervention study, compared to the consumption of control butter with higher amounts of SFAs (Tholstrup *et al*., 2006). Consumption of dairy products naturally enriched with CLA from pasture-fed cattle for 56 days did not significantly alter selected health risk factors (insulin sensitivity, body composition, circulating lipids as well as other disease risk factors) in healthy women when compared to consumption of dairy products with 3-fold less CLA, derived from grain-fed cattle (Brown *et al*., 2011). Livingstone *et al*. (2012) reviewed nine long-term human intervention studies that used modified dairy products (modified via cows' diet) to determine the effects on CVD risk markers where the majority of studies used modified butter and assessed changes in blood cholesterol as the main risk marker. Overall, the results suggest that modified dairy products may be beneficial to CVD risk in healthy and hypercholesterolaemic individuals; however, current evidence is insufficient and further studies are warranted.

Nutritional quality of bovine meat

Red meat is an important source of dietary protein for many people. Beef, in particular, is also a source of B vitamins and minerals including zinc and iron; indeed, it contains 2.5 times more iron than pork and 5 times more iron than poultry (Micinski *et al.,* 2012). Interestingly, the European Environment Agency reported that consumption of bovine meat in the EU decreased by nearly 14% between 2000 and 2013, coinciding with increased consumption of cheese and poultry meat (European Environment Agency, 2017). This reduction in consumption of bovine meat stems from associations between red meat, its saturated fatty acid content and risk of CVD and cancer. Of note, beef has a higher proportion of the saturated fatty acid stearic acid (C18:0) compared to other meats, which is regarded as being neutral in terms of raising blood cholesterol (Vargas-Bello-Pérez and Larraín, 2017; Grundy, 1994; EFSA, 2010). The link between beef and health risk is not the only reason for reduced consumption. Some EU countries reported a decline in beef consumption due to the correlation with outbreak of diseases such the bovine spongiform encephalopathy (Pires *et al.,* 2009). In this regard, correct consumer information related to health risks and safety is very important.

Fat in meat occurs in the form of glycerol esters, cholesterol, phospholipids and fatty acid esters deposited in intramuscular, intermuscular and subcutaneous adipose stores (Scollan *et al*., 2017). The intramuscular fat of beef varies between 20 - 50 g kg^{-1} and contains 450 - 480 mg 100 g^{-1} of SFAs, 350 - 450 mg 100 g^{-1} MUFAs and up to 50 g 100 g^{-1} PUFA (Bessa *et al*., 2015; Clonan *et al.,* 2016). The ratio of n-6:n-3 PUFA in ruminant meat is generally < 3.0, but in animals fed high amounts of cereal grains it has been reported to exceed 5.5 (Scollan *et al.,* 2006; Sinclair *et al*., 2007). Beef is also a source of CLA, and *trans* fats, the proportions of which vary depending on the breed and production system of the animals. CLA in retail beef has been reported to vary between 340 - 820 mg 100 g^{-1} total fatty acids (Aldai *et al*., 2009, 2010; Kraft, *et al*., 2008).

A number of studies have investigated the association between meat consumption and mortality or disease risk. The NIH-AARP Diet and Health Study investigated the link between meat intake and mortality with a cohort of 500,000 people aged 50 - 71 years and concluded that intakes of red meat and processed meat were associated with modest increases in total mortality, cancer mortality and CVD mortality (Sinha *et al*., 2009). This finding has been corroborated by other studies (Pan *et al*., 2012; Schwingshackl *et al*., 2017). A systematic review and meta-analysis of 111 cohort studies to quantify the dose-response between foods and beverages intake and colorectal cancer risk reported that colorectal cancer risk increases by 12% for each 100 g day^{-1} increase in red and processed meat intake, while the risk decreases by 13% for each 400 g day^{-1} increase of dairy products intake (Vieira *et al*., 2017). In a prospective cohort study of 51,683 Japanese people aged 40 - 79 years, Nagao *et al*. (2012) concluded that moderate meat consumption (up to ~100 g day^{-1}) was not associated with increased mortality from ischemic heart disease, stroke or total CVD. More recently, a meta-analysis of 24 randomised clinical trials revealed that consumption of ≥ 0.5 servings of total red meat / day does not impact blood lipids and lipoproteins or blood pressure (O'Connor *et al*., 2017). But as Vargas-Bello-Pérez and Larraín (2017) point out, there is no single definition of which meats are included in the term 'red meats' and most often it includes pork, beef and lamb and in some studies, processed meat as well. In this regard, in a systematic review and meta-analysis of the evidence, Micha *et al*. (2010) concluded that consumption of processed meats, but not red meats, was associated with higher incidence of CHD and diabetes mellitus. Given that modern evidence now questions the link between dietary SFA intake and CVD risk, it appears that compounds such as heme iron and sodium, in addition to other preservatives, may in fact contribute to the negative cardiovascular effects of certain meats (Mozaffarian, 2016).

Beef product quality from pasture-based feeding system

In the same way that ruminant animal feeding regimen alters the fatty acid profiles of milk, the fatty acid profiles of ruminant meats can also be adjusted through diet, enabling the production of healthier meat with decreased SFA contents and increased MUFAs and PUFAs. Pasture-based diets have been shown to increase CLA and vaccenic acid (C18:1, t11) content of beef, to increase the cholesterol-neutral fatty acid, stearic acid (C18:0), and reduce cholesterol-associated fatty acids including myristic (C14:0) and palmitic (C16:0) acids (Daley *et al.,* 2010). In addition, pasture feeding has been associated with increased β-carotene content in beef (Descalzo *et al*., 2005), as well as increased vitamin E and antioxidant capacity (De la Fuente *et al*., 2009; Realini *et al*., 2004) compared to grain-fed animals. For example, the intramuscular fatty acid composition of beef was significantly improved by including pasture in the diet (French *et al*., 2000). Indeed, increasing pasture intake and decreasing the proportion of concentrates resulted in a significant linear decrease in SFA concentration and in the n-6:n-3 PUFA ratio and significantly increased CLA concentration. Meat derived from steers reared and finished on pasture had higher concentrations of n-3 fatty acids, lower n-6:n-3 PUFA ratio, as well as higher magnesium and lower potassium content compared to meat from steers finished on concentrates (de Freitas *et al.,* 2014). In a review of the literature examining the impact of forage feeding versus grain finishing on beef nutrients in the United States, Van Elswyk and NcNeill (2014) concluded that 'beef cuts from cattle consuming mostly forage appear to be lower in fat than those from grain-finished beef, largely at the expense of MUFA.' However, the study by Van Elswyk and NcNeill (2014) also highlighted issues associated with sensory quality since changing the fatty acid content of beef can influence colour, flavour, sensory attributes and shelf-life (Scollan *et al.,* 2006). Steaks from pasture have been reported to be less tender than steaks from grain-finished beef (Blanco *et al.,* 2017). In addition, the external fat of pasture derived beef has been reported to be more yellow in colour (a consequence of increased β-carotene in adipose tissue). While flavour acceptability varies in terms of individual preference and cultural norms, trained sensory panellists reported that beef from pasture finished cattle lacked beef flavour and presented greater off-flavours than beef from grain-finished cattle (Duckett *et al*., 2013). Interestingly, a study investigating health information impact on the relative importance of beef attributes including its enrichment with PUFA and CLA on Spanish consumers revealed that informed consumers are willing to accept meat with a higher amount of visible fat once it is enriched with beneficial fatty acids (Kallas *et al.,* 2014) and a follow-on study revealed that informing consumers about beneficial fatty acids would favour marketing of beef enriched in n-3 PUFA through animal diet (Baba *et al.,* 2016).

Human intervention studies investigating the impact of beef as a result of the animal feeding system on human health are limited. A crossover dietary intervention involving 27 normocholesterolemic men investigated the effect of consuming 114 g ground beef patties / week for five weeks derived from pasture-fed cattle (low MUFA) or grain-fed cattle (high MUFA) on cholesterol (Gilmore *et al.,* 2011). It reported that the grain-fed derived pattie significantly increased HDL-cholesterol from baseline. Ten mildy hypercholesterolaemic men consumed hamburger patties derived from pasture-fed cattle (MUFA:SFA = 0.95) for five weeks and following a three week washout period consumed hamburger patties from grain-fed cattle (MUFA:SFA = 1.31) for another five weeks (Adams *et al.,* 2010). The high SFA burger (from pasture-fed cattle) significantly increased plasma palmitic acid, palmitoleic acid and triacylglycerols, decreased HDL cholesterol and had no effect on LDL-cholesterol. These studies reveal that pasture-derived beef can positively impact blood cholesterol profiles. Further research studies on the nutritional aspects of pasture-fed animals are, however, envisaged, in line with the increasing consumer awareness, that a natural animal feeding is correlated with animal and human health and the consumer desire for natural products, including animal derived ones (Gaggìa *et al*., 2011; Bolger *et al.,* 2017).

Conclusion

The nutritional composition, especially lipid profile and micronutrient (vitamin) composition of dairy and beef products can be modified through the animal's diet resulting in products which are nutritionally more beneficial in terms of human health. The lipid composition of milk and meat, in particular, is amenable to significant alterations generating fatty acid profiles which are more favourable towards a healthy lifestyle. Many studies have clearly indicated the advantages of pasture-feeding regimens over other feeding systems resulting in milk, milk-derived products and beef with increased PUFAs and CLA and reduced SFAs. The resulting products can also differ in terms of their technological properties and as we have seen with butter and beef, can differ in terms of texture and taste.

There is a paucity of studies investigating the influence of these products on human health. However, those which have been conducted suggest that dairy and beef produced from pasture-fed animals have the potential to favourably modify CVD risk factors. Further studies investigating the impact of pasture-derived products versus their grain-derived counterparts on human health are required to validate these findings. In addition, educating consumers on the role of the different fatty acids in promoting good health and on the levels of these fatty acids in food products is essential, enabling consumers to make informed decisions when choosing meat and dairy products as part of their daily diet.

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Comparison of grass utilisation performance of perennial ryegrass varieties

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Abstract

Grass utilisation is a key factor contributing to the profitability of grassland farms. This study examined the grazing utilisation of the 30 perennial ryegrass (*Lolium* perenne L.) varieties on the Irish Recommended List 2016. Plots were grazed by dairy cows from March to November 2017 on 11 occasions. Pre-grazing yield and height, post-grazing height and herbage removal were quantified. Varieties differed in grazing utilisation ($P < 0.001$), with post-grazing heights ranging from 3.7 to 4.8 cm. 'Residual grazed height' (RGH) was derived to measure grazing utilisation as the difference between predicted post-grazing height and actual post-grazing height. Most tetraploids outperformed diploids for grazing utilisation and despite desirable RGH values being negatively associated with grazing yield, varietal diversity indicated a potential for improvement. Further research is needed to determine the consistency of these differences and to determine how to assign an economic value to this grazing efficiency trait.

Keywords: grass utilisation, profitability, perennial ryegrass, residual grazed height, grazing yield

Introduction

Increased herbage utilisation increases the profitability of grazing systems largely by reducing the need for concentrate supplementation (Shalloo *et al.,* 2004). Differences in perennial ryegrass (*Lolium perenne* L.) traits such as total and seasonal herbage DM yield, persistence and quality are quantified in the Irish Recommended List (RL) trials to promote superior varieties. A new total economic merit index, the Pasture Profit Index (PPI), has been developed in Ireland to rank varieties by calculating the economic potential of each RL trait for ruminant production (O'Donovan *et al.*, 2016). Grazing utilisation refers to the proportion of leaf tissue removed by the grazing animals. Although it is not a RL trait, it is of interest as it may reflect animal performance at grass and may also reduce the mechanical intervention required to remove ungrazed herbage. Ungrazed herbage is undesirable as it reduces the quality of the sward in the subsequent grazing rotation. It is, therefore, important to develop a means to quantify grazing utilisation differences between varieties. The end use of such a 'grazing utilisation' characteristic would be to introduce a new trait into the PPI that would add greater weighting to the economic value given to varieties that support better animal performances. The objective of this experiment was to examine the grazing utilisation of the 30 perennial ryegrass (*Lolium* perenne L.) varieties on the Irish Recommended List 2016.

Materials and methods

All 30 varieties on the 2016 Irish RL were sown in 8 × 4.5 m plots in August 2016. The experiment was a randomised block design with three replicates of each variety. Fifteen diploid varieties with a range of heading dates were sown: AberChoice (09 June), AberMagic (31 May), Boyne (22 May), Clanrye (06 June), Drumbo (07 June), Glenroyal (05 June), Glenveagh (02 June), Kerry (01 June), Majestic (02 June), Nifty (27 May), Piccadilly (03 June), Rosetta (24 May), Solomon (21 May), Stefani (02 June), and Tyrella (04 June). Fifteen tetraploid varieties were also established: AberGain (05 June), AberPlentiful

(09 June), Alfonso (04 June), Aspect (06 June), Astonenergy (02 June), Carraig (24 May), Delphin (02 June), Dunluce (30 May), Kintyre (07 June), Magician (22 May), Navan (06 June), Seagoe (28 May), Solas (10 June), Twymax (07 June) and Xenon (11 June). The plots were rotationally grazed by dairy cows from early March to November 2017 with eleven grazings achieved. The residency time in the plots was never longer than 24 hours. Prior to each grazing a subsection of each plot was harvested with an Etesia motor harvester to a height of 3.5 cm. Length and width of each harvested subsection was recorded to determine herbage DM yield. Mown herbage was weighed and 0.1 kg dried at 90 °C for 8.5 hours to determine DM content. A Jenquip rising plate meter was used to measure the pre- and post- grazing heights. Herbage removed was determined at each grazing by adjusting the yield at 3.5 cm to the actual height grazed. Data were analysed in SAS (2011) with the variables block, variety and grazing events included in the model. The post-grazing height of each variety was predicted with a linear model, taking account of the pre- and post- grazing heights of all varieties. This prediction was compared to the actual post-grazing heights recorded after each grazing. The 'Residual Grazed Height' (RGH) was calculated as the average (3 blocks × 11 grazings) of the differences between actual post-grazing height achieved and the predicted post-grazing height. A negative RGH value indicates that a variety is grazed to a lower post-grazing height than predicted by the model and so had achieved good grass utilisation performance. In contrast, a variety with a positive RGH was grazed to a higher post-grazing height than predicted and so had a poorer utilisation capacity.

Results

Significant differences ($P < 0.001$) were found between varieties for pre-grazing height, post-grazing height and the proportion of the sward height removed through grazing. AberGain had the highest pre-grazing height at 11.8 cm, 2.2 cm higher ($P < 0.001$) than Astonenergy, which had the lowest pre-grazing height (9.6 cm). Astonenergy was also consistently grazed to the lowest post-grazing height, which was 1.08 cm lower than the highest post-grazing height recorded on Clanrye. Both AberGain and Xenon had the greatest proportion of their sward height removed through grazing, whereas Glenveagh and Solomon had the lowest proportion removed through grazing. The average predicted post-grazing height was 4.3 cm with a range of 4.1 to 4.5 cm. As the RGH values were defined as the difference between predicted and actual post-grazing heights, varieties with the best grazing performance would have a negative RGH and a high DM yield. These would be located in the top left quartile of Figure 1. Twymax was one of the varieties with the best grazing potential as it achieved a RGH of -0.18 and a grazed DM yield of over 15 t DM ha^{-1}. Astonenergy had the best RGH value but also one of the lowest grazed yields of 13 t DM ha^{-1}. In contrast, Clanrye produced the highest grazed yield of 16 t DM ha^{-1} but had a positive RGH of around

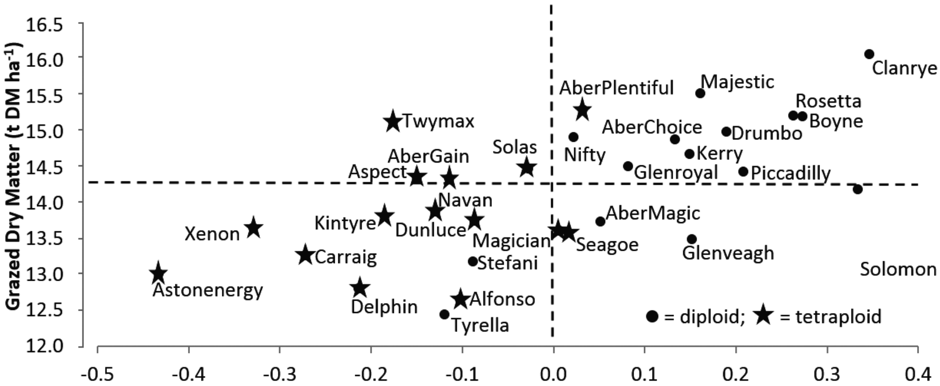

Figure 1. Relationship between residual grazing height and grazed herbage yield.

0.35, indicating that its actual post-grazing height was much higher than that predicted in the model. A higher post-grazing height makes Clanrye one of the least well adapted for grazing use overall. It was also notable that the tetraploid varieties were clustered largely on the left side of the graph with diploids more to the right. Only two diploids (Stefani and Tyrella) had a negative RGH, but with lower grazed yields than the other varieties. This indicated that tetraploids achieved a lower post-grazing height than diploid varieties. The overall pattern from Figure 1 was that as variety yield potential increased the RGH became more positive, and that varieties with negative RGH values tended to be lower yielding. There was, however, evidence that this was not an obligated relationship. Varieties such as AberGain, Alfonso, Aspect, Kintyre, Navan, Twymax and Tyrella had RGH values between -2.0 to -1.0, but differed in grazed yield potential between 12.5 - 15.2 t DM ha^{-1}, with Twymax and Tyrella the most extreme examples. Furthermore, AberGain, Aspect, Glenroyal, Piccadilly and Solas had similar grazed yields but differed in their RGH values.

Conclusion

Grass utilisation potential, as defined in this study, differed significantly between existing recommended varieties. A negative relationship between grazed yield and post-grazing height exists among these varieties. However, there is also clear evidence that some varieties did not conform to this relationship, implying that genetic diversity exists. Of interest in this aspect is the superior performance of most tetraploids compared with diploids with an equivalent grazed yield. The next steps will be to establish if these differences are consistent over years and seasonally, and to determine how to attribute a PPI economic value for this utilisation efficiency trait.

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Breeding grass varieties with increased magnesium content to prevent hypomagnesaemia in ruminants

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Abstract

Hypomagnesaemia ('grass staggers') is a potentially lethal disease of ruminants which have a poor capability for magnesium (Mg) storage in the body and must have sufficient Mg on a daily basis to prevent deficiency and subsequent disease. A high Mg content Italian ryegrass (*Lolium multiflorum* L.) cultivar (Bb2067) has been grown in a Mg fertiliser-response trial at two sites of contrasting soil Mg status, where initial data has shown no effect of Mg fertilisation on DM yield but all lines demonstrate a significant response to Mg fertilisation, while Bb2067 has consistently higher concentrations of Mg at all external Mg levels in cuts analysed so far. An associated controlled environment screen is aimed at identifying genetic markers linked to high Mg concentration in Bb2067 and will link to work on perennial ryegrass (*Lolium perenne* L.) at IBERS where five markers have been found with significant associations with tetany ratio. The markers will be used to develop new breeding material.

Keywords: *Lolium*, yield, magnesium, markers, cultivars

Introduction

Dietary magnesium (Mg) deficiency, caused by low dietary supply, and/or imbalance in relation to other cations can cause a range of dietary deficiency outcomes in grazing ruminants known as hypomagnesaemia ('grass staggers'). Hypomagnesaemia is widespread with high fatality rate and an average acute annual incidence of 1 - 4% in dairy cows but can reach levels of 20 - 30% in herds. Prevention is by supplying additional Mg (Suttle, 2010).

This paper will present initial results of work where the aim is to obtain genetic markers from a high Mg accumulating Italian ryegrass (*Lolium multiflorum* L.) cultivar (Bb2067). This variety was effective in considerably reducing hypomagnesaemia in sheep (Moseley and Baker, 1991). This cultivar was grown in a Mg fertiliser-response trial at two sites of contrasting soil Mg status along with a low Mg content cultivar Bb2068 and cvs RvP and Alamo. A controlled environment screening will also enable the identification of genetic markers in individual genotypes linked to high Mg concentration in Italian ryegrass which will link to the IBERS breeding populations where five markers have been found with significant associations with tetany ratio in perennial ryegrass (*Lolium perenne* L.). Ryegrass lines will be screened for these markers to develop new breeding material.

Materials and methods

Field plots (3 × 1.2 m) of four Italian ryegrass cultivars comprising Bb 2067 and Bb 2068, high and low Mg-containing lines, respectively, and the control cultivars RvP and Alamo, were sown at a seed rate of 35 kg ha^{-1} at IBERS, Aberystwyth on soil of the Rheidol series (Mg = 86 ppm, index = 2.6, pH = 5.8) and SASA, Edinburgh on soil of the Macmerry series (Mg = 193 ppm, index = 4.2, pH = 5.7) in summer 2016. All cultivars were subjected to four $MgSO_4$ fertiliser treatments (0, 30.15, 60.3 and 120.6 kg ha^{-1}) applied as foliar sprays after the first harvest. All plots were harvested seven times in the first harvest year with a Haldrup forage harvester at a cutting height of 5 cm. Fresh weights were measured and DM yields of each were calculated after drying a 300 g subsample from each plot in a forced draught oven at 80 °C for 48 hours. The dried sub-sample was retained and milled, to allow determination of the Mg content. The experiment was a completely randomised factorial design with four replicate blocks, four fertiliser treatments and four cultivars. Dry matter yield and Mg concentration were analysed by analysis of variance (ANOVA) using GenStat® Release 17 (www.vsni.co.uk, 2014) to discern any effects of location, fertiliser treatment and Italian ryegrass variety. Mineral analyses of all cuts from 2017 are ongoing. Mg data for cut 2 at Edinburgh is presented in Table 1.

Results and discussion

Increasing Mg levels in forage to prevent the incidence of hypomagnesaemia has been a common aim (Binnie *et al.*, 1996; Sleper *et al.*, 2002). The use of Magnet/Bb2067 in the project allows the new technique of marker assisted selection to be used on an existing variety with an established effect in hypomagnesaemia prevention and the information gained can be used in breeding new germplasm. The cultivars in the experiment differed significantly in DM yield (Table 1) at both locations, with the modern cv. Alamo significantly out-yielding the other cultivars. In turn, cv. RvP significantly out-yielded both Bb2067 and Bb2068 at the two locations. There were no significant differences in DM yield between Bb2067 and Bb2068 at both locations. The $MgSO_4$ fertiliser treatments did not affect yield. Previous work at both

Table 1. Total annual DM yield (t ha^{-1}) and magnesium concentration of four Italian ryegrass cultivars in the first harvest year subjected to four $MgSO_4$ fertiliser treatments.[1]

Variety	Aberystwyth DM yield (t ha^{-1})	Edinburgh DM yield (t ha^{-1})	Edinburgh Mg concentration cut 2 (mg kg^{-1})
Bb2067	20.93	19.79	2,525
Bb2068	21.25	19.78	1,818
RvP - control	22.76	20.21	1,993
Alamo	24.34	21.17	2,002
	***	***	***
SED	0.35	0.29	122
LSD_{05} (cf. RvP)	0.70	0.59	245
Fertiliser treatment			
$MgSO_4$_0	22.36	20.51	1,440
$MgSO_4$_1	22.14	20.06	1,904
$MgSO_4$_2	22.36	20.20	2,332
$MgSO_4$_3	22.39	20.19	2,664
	ns	ns	***
SED	0.35	0.29	122
LSD_{05}			245
Fertiliser * variety	ns	ns	ns

[1] $MgSO_4$_0 = 0 kg ha^{-1}, $MgSO_4$_1 = 30.15 kg ha^{-1}, $MgSO_4$_2 = 60.3 kg ha^{-1} and $MgSO_4$_3 = 120.6 kg ha^{-1}; total data is derived from a total of seven cuts.

locations had demonstrated a consistent increase in Mg content at all cuts over two harvest years (Penrose *et al.*, 2017) and while Mg levels at Aberystwyth were not above 2000 mg kg^{-1} in spring or 2500 in autumn, both levels suggested for hypomagnesaemia prevention (Todd, 1966). Mg levels at Edinburgh, however, did exceed both levels. Furthermore, Bb2067 reduced hypomagnesaemia in sheep (Moseley and Baker, 1991). Bb2067 had a significantly higher Mg concentration in Cut 2 at Edinburgh than the other three lines which did not differ significantly from each other. Mg fertilisation had a significant effect at all levels (Figure 1). All the lines showed a significant response to Mg fertilisation and Bb2067 had consistently higher concentrations of Mg at all external Mg levels (Figure 1).

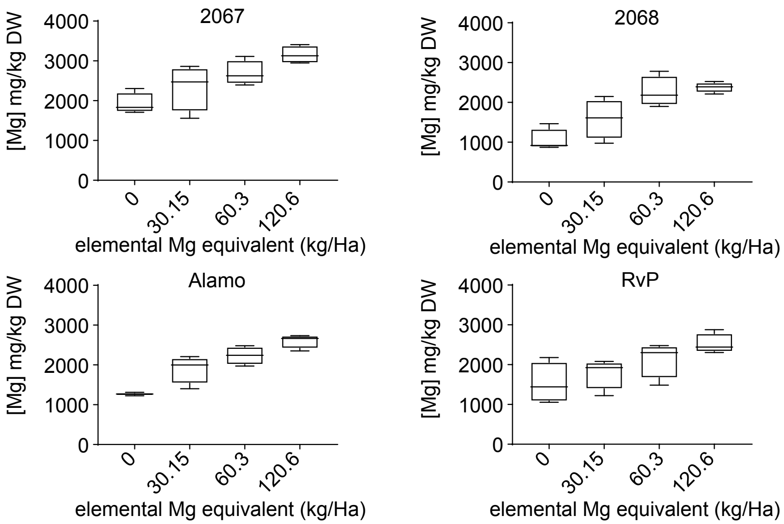

Figure 1. Magnesium concentration of four Italian ryegrass cultivars under four levels of fertilisation (Edinburgh, Cut 2).

Conclusion

Initial results on Bb2067 demonstrates that breeding for increased Mg uptake can be effective across a range of soil Mg levels. Completion of mineral analyses of other cuts from both sites will provide a source for discovering markers associated with increased Mg levels, which when linked to five markers having significant associations with tetany ratio in perennial ryegrass (L. Skot. 2017, pers. comm.), can be used to develop modern resilient cultivars to help prevent hypomagnesaemia.

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Yield stimulating legacy effect of sown legume abundance in a ley on the performance of a *Lolium multiflorum* following crop

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Abstract

A field mixtures experiment was conducted in Zürich over three years (2012-14) in which the sown legume proportion was 86, 50 or 14% in the seed mixtures and 100 or 0% in monocultures. In the spring of 2015, these swards were removed using herbicide and all plots were re-seeded with *Lolium multiflorum* L. monocultures, with the aim of studying soil transferred legacy effects of legumes on the performance of a following grass crop. The *L. multiflorum* L. was then harvested three times during 2015 (with the yield from each cut being summed for analyses) and once in spring 2016. Nitrogen (N) concentration from the combined harvests in 2015 was also recorded. A highly significant increase in the *L. multiflorum* L. annual biomass yield was detected in all treatments where legumes were the preceding crop compared to the non-legume monoculture in 2015 ($P < 0.001$). An effect continued into the following year, where treatments containing > 50% of sown legume proportion had a significantly greater biomass than the non-legume treatments ($P < 0.01$). Lastly, N concentration in the *L. multiflorum* L. sward from the 2015 harvest was also significantly increased in treatments with sown legumes over the non-legume monoculture ($P < 0.05$). These results explain how legume-induced effects on biomass could be sustained in mixed swards, even as the legume proportion declines to low levels, as had previously been observed in the COST 852 agro-diversity experiment.

Keywords: legacy effect, legumes, biomass, N concentration, following crop

Introduction

Numerous benefits of grass-legume mixtures over conventional grass monocultures have been thoroughly demonstrated, such as increased biomass yield, nitrogen (N) yield advantage and weed suppression (e.g. Finn *et al.,* 2013; Suter *et al.,* 2015). A less investigated aspect of these mixtures, however, is whether they induce any legacy effect in agricultural systems and what impacts such an influence may have on the following crop in a rotation. Previous studies have indicated that legume-induced effects on biomass can be sustained in mixed swards, even as the legume proportion declines to very low levels, e.g. the COST 852 agro-diversity experiment (Brophy *et al.,* 2017). The present study progressed a step further and targeted the performance of a following crop of *Lolium multiflorum* L. after the legume mixture had been completely removed with the aim of deducing any legume-induced legacy effects transmitted through the soil.

Materials and methods

Under the auspices of the EU-project AnimalChange, a field mixtures experiment was established at Zürich-Reckenholz (47° 26' 12" N, 8° 31' 51" E), conducted on a cambisol (top soil 42% silt, 26% clay, pH = 7.1) over a three year duration (2012-2014). The experiment utilised four model plant species, two grasses (*Lolium perenne* L., cultivar (cv.) Alligator and *Cichorium intybus* L., cv. Puna II) and two legumes (*Trifolium repens* L., cv. Hebe and *Trifolium pratense* L., cv. Dafila). The legume proportion of the seed mix was 86, 50 or 14% and 100 or 0% in monocultures, grown on a plot size of 3 × 5 m (Hofer *et al.*, 2016). In the spring of 2015 (21 April), these preceding swards were removed using a glyphosate herbicide and all plots were re-seeded via rotary harrow with a *Lolium multiflorum* L. monoculture. This following sward was subsequently harvested three times during 2015 (26 June, 10 August and 24 September,) and once in 2016 (27 April) and the biomass was measured at each harvest. In each plot, aboveground biomass was harvested in a central stripe of 5 × 1.5 m to a height of 7 cm using an experimental plot harvester (Hege 212, Wintersteiger). Nitrogen concentration was measured using on a CN elemental analyser. Data were analysed by analysis of variance.

Results and discussion

A highly significant increase in the *L. multiflorum* annual biomass yield was seen in all legume containing treatments (even the 14% plots) compared to the non-legume monoculture in 2015 (Figure 1A, $P < 0.001$). Moreover, there was a linear trend of legume proportion on yield: the greater the sown legume proportion, the greater the yield of *L. multiflorum* ($P < 0.001$). Legume effects continued into the following year, though at a reduced magnitude, where treatments containing > 50% sown legumes had a significantly higher biomass than the non-legume treatments (Figure 1B, $P < 0.01$). Even in spring 2016, a positive linear trend of sown legume abundance on yield was observed ($P < 0.01$).

Nitrogen concentration from the biomass of the 2015 harvest was also significantly increased in all legume-containing treatments compared to the non-legume monoculture (Figure 2, $P < 0.05$). This increase in the performance of a following crop demonstrates an additional advantage to sowing legume-containing mixtures. It also helps to provide an explanation for the observations of the aforementioned COST 852 agro-diversity experiment, in which a yield stimulating advantage of legume-containing mixtures were sustained even as the legume proportion in the mixture declined (Brophy *et al.*, 2017). The sustained positive influence on plant performance seen in this experiment may be a consequence of previously suggested mechanisms, such as N being made available from decaying root exudates, or an increase in soil organic matter derived from the fixation of atmospheric N_2 by the previous legume component of the ley (Suter *et al.*, 2015).

Additionally, these results would suggest a role being played by the soil microbiome, as soil microorganisms are mainly responsible for the mineralisation of organically-bound N (Schwartz *et al.*, 1991). Such a possibility warrants further investigation examining both the composition and functional potential of the microbiome and the role this may have played in the observed legume-induced legacy effect on following crop performance.

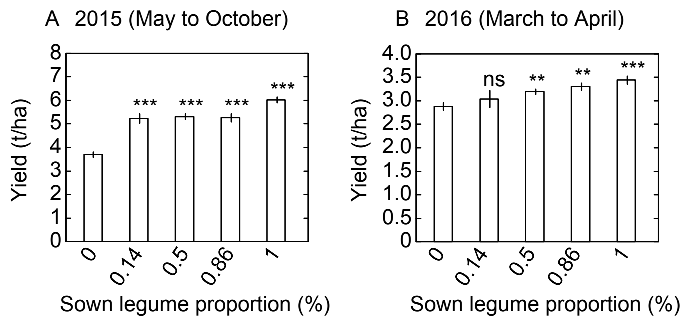

Figure 1. Biomass yield (t ha^{-1}) (± 1 standard error) from the harvest of the following crop *Lolium multiflorum* L. sward in 2015 (A) and 2016 (B) from plots which had a previous ley with a legume proportion in the seed mix of 0, 14, 50, 86 and 100%. Yields of three harvests were summed to give the total annual yield in 2015 (A), while the first harvest of spring 2016 is shown (B). Asterisks denote a significant difference to the sward containing no legumes. *** $P < 0.001$, ** $P < 0.01$, ns: $P > 0.05$.

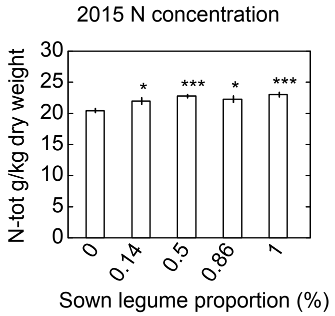

Figure 2. Nitrogen concentration (N-tot g kg^{-1} dry weight) in biomass of the following crop of *Lolium multiflorum* L. from the 2015 harvest from plots which had a previous ley sown with a seed mix containing 0, 14, 50, 86 and 100% legume proportion. Asterisks denote a significant difference to the sward containing no legumes. *** $P < 0.001$, ** $P < 0.01$, ns: $P > 0.05$.

Conclusions

These results highlight additional advantages of sowing legume mixtures over grass monocultures, as they demonstrated a soil transferred yield-stimulating legacy effect on the following crop in rotation. They can also explain how legume-induced effects on biomass could be sustained in mixed swards, even as the legume proportion declines to low levels, as was observed in the COST 852 agro-diversity experiment.

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Enhancing Sulla (*Hedysarum coronarium* L.) introduction to different soil types through inoculation with rhizobia strain

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Abstract

Sulla (*Hedysarum coronarium* L.) is a very nutritious and productive forage legume with great potential for livestock in Mediterranean farming systems. Its cultivation in Sardinia is confined to areas where its native specific rhizobium is available. Although a large proportion of Sardinian soils have the potential to grow Sulla, its use is limited by the absence of the inoculation practice with appropriate rhizobia strain. Forty three dairy sheep farms, located in different areas of Sardinia, were selected to introduce inoculated Sulla in paddocks (1or 2 ha) for the first time. The altitude of the sites ranged between 1 and 650 m above sea level (a.s.l); soil texture varied between clay, sandy-clay to loamy soil with pH (H_2O) ranging from 5.4 to 8.5. On each farm, plant establishment and nodulation scores were measured. Inoculation was shown to be a successful means of establishing Sulla in soil considered hostile to the species.

Keywords: legumes, forage species, livestock farming, root-nodule bacteria

Introduction

The sustainability and profitability of grazing farm systems is related to the ability of the farmers to match energetic requirements of ruminants with pasture production throughout the year. However, in Mediterranean environments, because of the high variability of edaphic conditions, it is not always possible to match the feed requirements with forages produced *in situ*, therefore, farmers need to acquire the extra food from outside of the farm incurring extra costs to maintain animal condition score at acceptable levels. Persistent and productive forage species are always sought by farmers, sometimes with great difficulty and high costs because of high market prices and environmental constraints such as soil type and low annual rainfall. Sulla (*Hedysarum coronarium* L.) is a productive, deep-rooted, short-lived perennial pasture legume that is grown throughout Mediterranean countries (Foote, 1988). It is commonly found in clay calcareous soil with alkaline pH. Its deep-rooted system gives it the capacity to maintain extended periods of spring growth, and its perenniality allows rapid re-growth in the second autumn. Additionally, the high nutritive value of Sulla improves milk production and, due to its condensed tannins content, has anti-bloating and internal parasite control properties in sheep (Terrill *et al*., 1992; Molle *et al*., 2003). The microsymbionts of Sulla display a high level of specificity for nodulation and nitrogen (N) fixation. When effectively nodulated, Sulla plants have the ability to biologically fix large quantities of N, increasing paddock fertility (Yates *et al*., 2015). Although it is widely used as a forage legume in Mediterranean Europe, only a limited area of Sulla is grown in Sardinia. Its cultivation is mainly confined to areas where its native specific rhizobium is available and it is totally absent in the rest of the island. The objective of this work was to demonstrate that Sulla can grow successfully in other Sardinian soil types as long as the seed is inoculated with the appropriate rhizobia strain.

Materials and methods

Forty two dairy sheep farms, located in different areas of Sardinia, were selected to introduce, for the first time, inoculated Sulla in paddocks of 1 to 2 ha. In 11 farms out of 42, two paddocks with different soil characteristics were selected. In the other 31 farms, one paddock was seeded. Each paddock was characterised and soil samples were taken to determine soil texture and chemical composition. Soil pH was measured in 1:2.5 soil:water suspensions, the organic matter content was determined using the Walkley and Black (1934) method. Total N and available P were determined using the Kjeldahl and Olsen methods, respectively, exchangeable K and Ca were determined by flame atomic absorption spectroscopy following ammonium acetate extraction. Total calcium carbonate was determined quantifying the CO_2 produced after acid dissolution and active carbonate was determined using the ammonium oxalate method.

A few hours before seeding, Sulla was inoculated with a *Rhizobium sullae*, strain WSM1592 (Yates *et al*., 2015). Peat slurry was prepared mixing the peat with the seed coating adhesive (250 g of peat, 1000 ml adhesive per 25 kg of seed). Seed was inoculated by mixing the slurry with the seed and then seed was pelleted with fine lime. A small area in each paddock was seeded with un-inoculated Sulla seeds as a control. Paddocks were sown in autumn 2014. In each paddock, plant establishment numbers were recorded approximately 45 days after seeding in 30 quadrats (900 cm^2 each) randomly positioned in each paddock. Three months after seeding, 15 plants per paddock were carefully removed and roots carefully washed and assessed for nodulation (Howieson and Dilworth, 2016). Paddocks were scored in 2014 and 2015 for ground cover and vigor (0 to 5). It is known that soil pH is the main constraint to optimal Sulla nodulation and growth (Yates *et al*, 2015); therefore the paddocks were separated in different pH groups. The first group included 15 paddocks with soil pH < 6.5. The second group included 15 paddocks with soil pH range between 6.5 and 7.5. The last group included 23 paddocks with pH > 7.5. Data were analysed by Anova model. Differences between treatments were assessed by Duncan T tests ($P < 0.05$, SAS Institute, 2002).

Results and discussion

The altitude of the sites ranged between 1 and 650 m a.s.l; soil texture varied between clay, sandy-clay to loamy soil. Soil fertility of the paddocks was generally high, however, the pH varied between 5.4 and 8.5 (Table 1). The un-inoculated plants across the three soil groups generally showed suboptimal levels of nodulation, although it was greater in alkaline soils compared to the others, suggesting that the background rhizobium levels were inadequate or the N fixation efficacy of the native rhizobia was very poor (Table 2). On the other hand, inoculated plants were all moderately nodulated, showing no symptoms of N deficiency and no significant differences between the paddock groups. Ground cover and

Table 1. Soil characteristics of the 53 paddock sown to Sulla. Values with different letters within column are significantly different ($P < 0.05$).

pH	pH (H_2O)		Organic matter	Total N	Exchangeable K	Available P	Total carbonate	Active carbonate	Exchangeable Ca
	Range	Average	g kg^{-1}	g kg^{-1}	mg kg^{-1}	mg kg^{-1}	g kg^{-1}	g kg^{-1}	mg kg^{-1}
< 6.5	5.4 - 6.4	5.99 (0.07)	28.65 (3.66)	1.80 (0.20)	242.7 (51.3)	13.5^{b} (2.21)	4.8^{b} (4.84)	1.93^{b} (1.93)	$1{,}960.1^{b}$ (402)
6.5 - 7.5	6.5 - 7.5	6.94 (0.08)	31.5 (2.64)	2.02 (0.16)	246.7 (56.8)	21.2^{a} (2.93)	12.7^{b} (9.84)	8.47^{b} (8.47)	$3{,}593.3^{a}$ (534)
> 7.5	7.6 -8.5	8.04 (0.05)	23.85 (1.75)	1.78 (0.11)	314.7 (53.6)	19.0^{ab} (1.46)	130.9^{a} (37.25)	30.20^{a} (8.54)	$4{,}431.6^{a}$ (302)
P		< 0.001	ns	ns	ns	0.054	0.003	0.024	< 0.001

Table 2. Seedlings establishment, nod efficiency, crop scores (1 to 5) in 2014 and 2015. Values with different letters within column are significant different ($P < 0.05$).

pH	No. of paddocks	Seedling (n m^{-2})	Nod efficiency		Sowing year-2014		Second year-2015	
			Inoculated score	Uninoculated score	Vigor score	Ground cover score	Vigor score	Ground cover score
< 6.5	15	182.9 (21.8)	2.26 (0.41)	0.43^{b} (0.25)	2.17^{b} (0.40)	2.38^{b} (0.38)	3.2^{b} (0.32)	1.34^{b} (0.36)
6.5 - 7.5	15	205.6 (30.3)	3.06 (0.21)	0.85^{ab} (0.41)	2.09^{b} (0.32)	3.27^{ab} (0.24)	3.44^{ab} (0.47)	1.57^{ab} (0.36)
> 7.5	23	198.6 (17.7)	2.97 (0.28)	1.47^{a} (0.27)	3.07^{a} (0.26)	3.43^{a} (0.23)	4.26^{a} (0.20)	2.35^{a} (0.27)
P		ns	ns	0.065	0.046	0.057	0.030	0.062

vigor of the Sulla plants within groups and between 2014 and 2015 were similar; however, the group that included paddocks with pH > 7.5 was always more productive (Table 2).

Conclusion

The results from this research show that inoculated Sulla can be grown successfully in different soil types where the species is not traditionally recommended. Some of the paddocks had a challenging soil pH (5.4) for the growth of Sulla; however, a proper inoculation practice seems to have partially overcome past problems. Further studies are currently underway to select elite rhizobia strains for acidic soils and when completed we will provide more information to promote the use of the Sulla species across a broader range of environments.

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Red clover cultivars of Mattenklee type show higher yield and persistence than Ackerklee type

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Abstract

Specialised dairy farmers have increased interest in multi-year red clover (*Trifolium pratense* L.)-ryegrass (*Lolium spp.*) ley pastures because of their high productivity and protein concentration. However, the adoption of such mixtures is restricted because of the poor persistency of many red clover cultivars (cv.) currently used. Extending the duration of the clover ley would reduce costs for seeding and have positive effects on yield, carbon sequestration and soil biodiversity. We aimed to assess dry matter yield (DMY), persistence and nutritive value of four Mattenklee and four Ackerklee cv., and to investigate the underlying plant morphological traits. We conducted a four-year field experiment with red clover-ryegrass mixtures, in combination with a short-term pot experiment. In the field, Mattenklees showed on average 42% higher production compared to Ackerklees in the third and fourth year. In the fourth year, Mattenklees had slightly lower digestibility and protein concentration compared to Ackerklees; however, the digestible dry matter and the protein yield were higher for Mattenklees. Both persistence and nutritive value of the different red clover cv. were closely correlated to stem length. For stem length there was close correlation between the pot and the field experiment, suggesting that this may be an important trait for plant breeding.

Keywords: nutritive value, morphology, breeding, plant traits, *Trifolium pratense* L.

Introduction

In the Netherlands, there is increasing interest in red clover for ley pastures with dairy farmers, who see its value and potential in terms of symbiotic nitrogen fixation, protein concentration and production capacity (Iepema *et al.*, 2006). One of the main constraints that restricts the adoption of such mixtures is the poor persistency of the red clover cultivars (cv.) currently used by farmers (Iepema *et al.*, 2006). Extending the duration of the clover ley beyond the two to three years currently achieved, would reduce costs for seeding and have positive effects on carbon sequestration and soil biodiversity (van Eekeren *et al.*, 2008). In Switzerland, highly persistent and locally adapted red clover landraces, the so-called 'Mattenklees', show a high level of survival after three growing seasons in swards mixed with grass (as opposed to the traditional 'Ackerklees'). We aimed to assess dry matter yield (DMY), persistence and nutritive value of four Mattenklee and four Ackerklee cv., and to investigate the underlying plant morphological traits.

Materials and methods

A four-year field experiment was conducted at Esbeek, the Netherlands. Eight red clover cv. including four Ackerklee landraces (cv. Avanti, Lemmon, Maro and Taifun) and four Mattenklee landraces (cv. Fregata, Larus, Milvus and Pavo) were sown (270 viable seeds m^{-2}, ca. 7.1 kg ha^{-1}) in a mixture with diploid perennial ryegrass (cv. Mathilde, 30 kg ha^{-1}) in August 2011. The trial was arranged in a randomised block design with four replicates and plots were 4 × 8 m. The trial was managed with a four-cut regime and measurements were undertaken during 2012, 2014 and 2015. No measurements took place during 2013, as this year was deemed less relevant in terms of persistence. Total dry matter yield at each harvest was determined by cutting a strip of 0.84 × 4 m within each plot with a front bar mower, leaving a sward stubble height of ca. 6 cm. The samples were weighed and a sub-sample was dried in a forced-draught oven at 70 °C for 24 h for dry matter (DM) analysis. At each harvest, the red clover content was determined on a fresh sub-sample of at least 200 g. The separated red clover sub-samples from the 1st cut in 2015 were dried and analysed for crude protein (CP) and digestible organic matter in the dry matter (DOMD). Before the first harvest in 2015, plant morphological measurements including plant density, shoot weight, leaf: stem-ratio, specific leaf area and stem length were determined. In addition to the field experiment, a pot experiment was established in a greenhouse, at Wageningen University, in which the eight red clover cv. were sown in four replicates in August 2014. After eight weeks the plants were harvested, morphological traits were determined and plants were oven dried at 70 °C for 72 h for DM determination. For more details we refer to Hoekstra *et al.* (2017). Data were subjected to analysis of variance in Genstat to test for a cv. effect (n = 4) or a clover type effect (Mattenklee vs Ackerklee, n = 16). Spearman correlation coefficients were conducted to determine the association between different morphological traits, nutritive value and persistence indicators.

Results and discussion

In the field, the red clover DMY and to a lesser extent the herbage DMY was significantly ($P < 0.01$) higher for Mattenklees compared to Ackerklees during the third (2014, increase of 33 and 5% respectively) and fourth (2015, increase of 54 and 8%) production year. The two types showed no significant difference during 2012 (Table 1). This was in line with our expectations and indicates that the breeding effort into more persistent red clover cv. is effective (Lehmann and Briner, 1998) under the local conditions in the Netherlands.

Dry matter yield and persistence of the different red clover cv. were closely correlated to plant morphological traits, in particular, stem length (Table 2). Higher stem length may give the red clover a competitive advantage for light competition, resulting in higher yield and persistence, which was also found by Herrmann *et al.* (2008). The stem length was negatively correlated to red clover CP and DOMD concentration (Table 2), which tended to be lower for Mattenklee compared to Ackerklee cv. However, in the first cut in 2015, CP yield was 38% higher and DOMD yield was 10% higher for Mattenklees compared to Ackerklees. Interestingly, for stem length, there was close correlation between

Table 1. Mean red clover and herbage dry matter yield (DMY) of the four Ackerklee (AK) and four Mattenklee (MK) ryegrass mixtures in 2012, 2014 and 2015.

Cultivar		Red clover DMY (t ha^{-1})				Total herbage DMY (t ha^{-1})			
		2012	2014	2015	Yield index[1]	2012	2014	2015	Yield index
Avanti (AK, 4n)		6.2^{cde}	7.4^{c}	4.8^{def}	80^{ab}	11.0^{bc}	12.4^{d}	10.6^{bcd}	98^{bc}
Lemmon (AK, 2n)		5.9^{de}	7.9^{c}	3.7^{f}	68^{a}	10.9^{bc}	12.7^{cd}	10^{cd}	92^{ab}
Maro (AK, 4n)		7.7^{a}	9.1^{bc}	4^{ef}	53^{a}	12.6^{a}	14.3^{a}	9.8^{d}	79^{a}
Taifun (AK, 4n)		7.5^{ab}	7.9^{c}	5de	68^{a}	11.7^{ab}	12.9^{bcd}	10.8^{abc}	94^{ab}
Fregata (MK, 4n)		6.7^{abcd}	10.7^{ab}	6.8^{b}	105^{bc}	11.4^{bc}	13.7^{abc}	11.6^{a}	104^{bc}
Larus (MK, 4n)		7.4^{abc}	11.1^{a}	8.4^{a}	116^{c}	12.0^{ab}	13.8^{abc}	11.2^{ab}	94^{ab}
Milvus (MK, 2n)		5.4^{e}	9.9^{ab}	6.3^{bc}	125^{c}	10.2^{c}	13.8^{abc}	11.2^{ab}	112^{c}
Pavo (MK, 2n)		6.4^{bcde}	11^{a}	5.2^{cd}	82^{ab}	11.6^{ab}	14.1^{ab}	10.5^{bcd}	92^{ab}
SED		0.58	0.86	0.53	14.9	0.59	0.61	0.45	7.3
P-value		**	***	***	***	*	*	**	*
Mean Type	AK	6.8	8.1	4.4	67	11.6	13.1	10.3	91
	MK	6.5	10.7	6.7	107	11.3	13.8	11.1	100
P-value		ns	***	***	***	ns	*	**	**

[1] Yield index = DMY 2015 / DMY 2012 × 100%.

Table 2. Mean plant morphological traits in the field experiment during the first harvest in 2015 for Ackerklee (AK) and Mattenklee (MK) cv. and coefficients of correlation of these traits with red clover yield and crude protein (CP) and digestible organic matter (DOMD) concentration in 2015 and morphological traits in the pot experiment.

Morphological traits 2015	Mean				Correlation (r)			
	AK	MK	SED	P^1	Clover DMY	CP	DOMD	Morphology pot exp
Plant density (# m^{-2})	21.1	32.5	2.17	***	0.93 ***	-0.60	-0.58	na
Shoot weight (g $plant^{-1}$)	9.5	12.7	1.26	*	0.72 *	-0.65	-0.57	0.68
Leaf: stem ratio (g g^{-1})	0.56	0.51	0.023		-0.28	0.63	0.49	0.68
Specific leaf area (cm^2 g DM^{-1})	235	228	7.9		-0.68 ·	0.12	0.29	0.41
Stem length (cm)	38.6	47.6	1.52	***	0.85 **	-0.75 *	-0.75 *	0.77 *

[1] *P*-value: · = $P < 0.1$; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$.

the measurements from the pot and the field experiment (Table 2). The apparent robustness of this measurement strengthens the potential of this trait use in plant selection and breeding.

Conclusion

In line with our hypothesis, the Mattenklees showed a higher DMY in the third and fourth year of production compared to the Ackerklees, indicating that these cv. are suitable for inclusion in a multiple year grass-clover ley. Both persistence and nutritive value of the different red clover cv. were closely correlated to stem length. Stem length showed close correlation between the pot experiment and the field experiment, indicating that this may be an important parameter for breeding.

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The relationship between phenological development of red clover and its feed quality in mixed swards

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Abstract

Red clover (*Trifolium pratense* L.) is an inferior competitor for light during spring growth in grass-clover mixtures, whereas it can dominate the yield harvested later in summer. This leads to a disproportional content of clover in total biomass between harvests, which may cause challenges for cattle feeding. We have investigated whether inclusion of an early versus a late heading red clover variety could overcome these challenges. In a field trial harvested three times per season, each of the varieties were grown together with two different grass mixtures. The early variety was taller and heavier and constituted a higher proportion of total biomass, but developed less leaves and shoots per plant than the variety initially classified as late. Rate of phenological development of the two did not differ during spring growth, but the early variety was at more advanced stages at the second and third cut in summer. The early variety had lower crude protein and net energy concentrations at all harvests, whereas it contained more neutral detergent fibre (NDF) and indigestible NDF.

Keywords: feed quality, phenology, *Trifolium pratense* L.

Introduction

Red clover (*Trifolium pratense* L.) is often grown together with temperate grasses in mixed swards under two - three cut systems to increase stability, DM yield and forage quality of mixed swards (Halling *et al.*, 2002). During spring, red clover is an inferior competitor for light in erect grass stands and thus constitutes a lower proportion of total biomass, whereas later in summer it may dominate the total yield of moderately fertilised swards (Eriksen *et al.*, 2014; Riesinger and Herzon, 2008). This disproportional content of red clover in the first and later harvests may lead to differences in feed quality that may cause challenges for farmers with difficulties in feeding with more than one type of silage at a time. The competitive ability of red clover grown together with grasses may be related to its rate of phenological development. So far, the varieties bred and approved for Norwegian conditions seem to be slow in their development in spring. It has been suggested that earliness is negatively correlated with winter persistence (Pulli, 1988). In this study, we have compared an early and a late variety to study if growing early varieties could overcome the challenges of disproportionality in yield proportion and feed quality between the harvests.

Materials and methods

A field trial was established in 2013 at a research farm (Kvithamar) of the Norwegian Institute of Bioeconomy Research (NIBIO) in Stjørdal, mid-Norway (63° 30 N, 10° 54 E; elevation 30 m a.s.l.). Two red clover varieties, one classified as early and one as late by their respective breeders were each sown together with two different grass mixtures according to a randomised block design with four treatments in three replicates/blocks. One grass mixture was composed of Barpasto, Calibra, Dunluce, Prana, Storm, Figgjo, Birger, Fia and Trygve varieties of perennial ryegrass (*Lolium perenne* L.), while the other grass mixture consisted of the timothy (*Phleum pratense* L.) variety Grindstad and the meadow fescue (*Festuca pratensis* Huds.) variety Fure. The late red clover variety was Betty (Swaløf Weibull AB, Sweden) and the early variety was Atlantis (Norddeutsche Pflanzenzucht Hans-Georg Lembke (NPZ), Germany). The grass-red clover mixture was sown at two seeding rates of 35 kg ha^{-1} (5 kg red clover + 30 kg ryegrass) and of 25 kg ha^{-1} (5 kg red clover + 12.5 kg timothy + 7.5 kg meadow fescue). In 2014, three harvests were taken (5 June, 21 July and 1 September) and 160 kg mineral N ha^{-1} was supplied in a compound fertiliser (distributed as 0.5, 0.25, 0.25 in spring, after the first and second cut, respectively). Rate of phenological development of red clover plants was recorded as mean stage by count (MSC), modified from Moore *et al.* (1991). Red clover proportion in the total biomass and leaf proportion of red clover plants were recorded by manual sorting of subsamples from all plots in two replicates at each harvest. Forage quality as described by the content of crude protein (CP), heat stable amylase neutral detergent fibre (aNDF), NDF digestibility (NDFD) and net energy for lactation (NEL) was analysed by near infrared reflectance spectroscopy after local calibration based on chemical analysis of a subset of samples at Dairy One Forage Testing Laboratory in the USA. For each harvest, all parameters were analysed by analysis of variance using the GLM procedure in SAS (release 9.3, 2002-2010, SAS institute Inc., Cary, NC, USA). Red clover variety and grass mixture were regarded as fixed factors and block as random.

Results and discussion

The two red clover varieties did not differ in rate of phenological development and leaf proportion at first harvest (Table 1). However, the early variety Atlantis constituted a higher proportion of total biomass of the grass-clover sward than the late variety Betty. The late variety Betty had higher NDFD and higher concentration of CP and NEL than the early variety Atlantis. Differences in NEL were only significant when red clover was grown together with the perennial ryegrass mixture ($P < 0.05$). At the second harvest (Table 1), Atlantis was at a higher stage of phenological development and constituted a higher proportion (0.54) of total biomass than Betty (0.32) did. Furthermore, Betty had a higher leaf

Table 1. Stage of phenological development expressed as mean stage by count (MSC) and feed quality of early (Atlantis) and late (Betty) red clover varieties. Red clover proportion is presented as clover DM share of total biomass DM, while leaf proportion, crude protein (CP) and heat stable amylase neutral detergent fibre (aNDF) are presented as g kg^{-1} of clover DM. Clover NDF digestibility (NDFD) is presented as g kg^{-1} of NDF, while net energy of lactation (NEL) is presented as feed unit (FEm = 6.9 MJ kg^{-1} DM) per kg clover DM. Presented values are means for two grass mixtures.[1]

Variety	MSC	Clover prop	Leaf prop, g kg^{-1} DM	CP, g kg^{-1} DM	aNDF g kg^{-1} DM	NDFD g kg^{-1} NDF	NEL FEm kg^{-1} DM
First harvest							
Betty	1.62	0.08	850	260	350	770	0.95
Atlantis	1.66	0.14	780	210	360	690	0.93
S.E	0.13	0.03	0.60	5.90	1.70	10.8	0.01
P value	ns	0.05	ns	< 0.001	ns	< 0.01	< 0.01
Variety × grass *P* value	ns	ns	ns	ns	ns	ns	0.03
Second harvest							
Betty	1.63	0.32	900	190	380	550	0.79
Atlantis	2.53	0.54	590	170	410	500	0.77
S.E	0.15	0.05	0.80	1.80	3.10	6.50	0.005
P value	< 0.01	0.001	0.02	< 0.01	< 0.01	< 0.001	ns
Variety × grass *P* value	ns	ns	ns	0.01	0.03	ns	0.01
Third harvest							
Betty	1.42	0.53	980	220	350	590	0.87
Atlantis	2.06	0.59	610	210	380	550	0.84
S.E	0.12	0.04	0.30	2.90	2.40	8.10	0.006
P value	0.01	ns	< 0.001	0.02	< 0.01	< 0.01	0.03
Variety × grass *P* value	ns	ns	ns	ns	ns	ns	ns

[1] ns = non significant ($P > 0.05$); S.E. = standard error.

proportion, NDFD and higher concentration of CP and NEL. The aNDF concentration was lower than for Atlantis. Red clover grown together with perennial ryegrass had higher CP and lower aNDF than red clover grown together with timothy and meadow fescue ($P < 0.05$). Differences in NEL between the varieties were significant only when sown with the perennial ryegrass mixture ($P < 0.05$). During the third harvest (Table 1), a similar pattern (as observed in the second harvest) of variety ranking was observed in phenology, morphology and forage feed quality parameters. Red clover proportion of total herbage was much lower in the first harvest (0.08 and 0.14 for Betty and Atlantis, respectively) compared with the second (0.32 and 0.54) and third harvests (0.53 and 0.59). This indicates that growing an early maturing red clover variety does not overcome the problem of low clover proportion in mixed swards during spring. However, during the summer, the early variety Atlantis had a higher rate of phenological development than the late variety Betty and could increase the clover proportion in mixed swards. The early variety Atlantis had lower herbage feed quality in all cuts than the late variety Betty as seen by lower NDFD and lower concentration of CP and NEL (except at the second harvest). One likely reason for lower CP and NDF digestibility in the early variety Atlantis was the lower leaf proportion of total clover plant biomass. The early variety Atlantis was taller (data not shown) and heavier than the late variety Betty and was more competitive for light in mixed stands, but spent more energy on stem growth than leaf growth, which results in lower feed quality.

Conclusion

The findings of the present study do not provide evidence that growing early varieties may overcome the challenges related to disproportional content of red clover between the first and later harvests. The rate of phenological development differed between the two investigated varieties in summer only, and at this time, the phenological advancement was positively correlated to clover proportion but negatively to forage feed quality. There may, however, be other varieties or germplasm available that are earlier heading than the ones investigated here.

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Performance of legume-based annual forage crops in a Mediterranean environment

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Abstract

Legume-based annual forages could be pivotal for the sustainable intensification of forage production in drought-prone environments. A three year study aiming to optimise the composition of these crops was carried out under Mediterranean conditions (Sardinia). Four legumes (semi-dwarf and tall type field pea (*Pisum sativum* L), common vetch (*Vicia sativa* L.) and Narbon vetch (*Vicia narbonensis* L.)) and two cereals (triticale (*x triticosecale*) and oats (*Avena sativa* L.)) were grown as pure stands and legume-cereal mixtures. Dry matter yield (DMY), mixture composition and weed content were determined in each cropping year. In addition, farmers were involved in crop visual assessment in two cropping years. Both field pea tall type and common vetch showed the highest DMY in mixtures with oats (7.4 t ha^{-1}), and the highest legume content in mixtures with triticale. Narbon vetch yielded the lowest DMY. Vetch monocultures and mixtures had the lowest weed content. The vetch-oat mixture obtained the top score by farmers' assessment. The results of this trial encourage the use of winter cereal-legume mixtures to improve yield stability and productivity in Mediterranean environments.

Keywords: legume-cereal mixtures, yield stability, forage pea, Narbon vetch, common vetch

Introduction

In the Mediterranean Basin, typical animal added-value products sustain the agricultural economy. Their production is based on extensive livestock systems, where rangelands, fallow and cereal stubbles are the basis for feeding grazing animals. The insufficiency of feed protein and high-quality feed together with the variability of DM production due to decreasing and more erratic rainfall (FAO, 2010) are the main threats to these systems. Annual forage legumes could be advantageously used in mixtures with cereals to ensure a high protein content in forage and possibly increase DM yield (DMY) relative to the mean value sown as monocultures (Chapagain and Riseman, 2014). Currently, there is insufficient information on the best legume species and type of cultivation for Mediterranean environments. In this study, we aimed to optimise annual forage crop production by: (1) assessing legume-cereal mixed crops based on common vetch (*Vicia sativa* L.), Narbon vetch (*Vicia narbonensis* L.) and forage pea (*Pisum sativum* L.); (2) using the farmers' participatory assessment to verify the end-user acceptance of novel crops.

Materials and methods

The experiment was carried out under rainfed conditions during three cropping years (2013 - 2016) in north Sardinia, Italy (40°84'N, 8°82'E, 24 m a.s.l.). The climatic conditions of the site were warm Mediterranean, long-term rainfall which was 550 mm y^{-1}, mostly concentrated between October and May. The soil was alluvial, with a pH of 7.8. Three legume species were tested: forage pea semi-dwarf/semi-leafless type (cv. Kaspa; P1) and tall size/semi-leafless type (line 2/38b; P2), Narbon vetch (cv. Bozdag; N) and common vetch (cv. Barril; V); together with the cereal oats (*Avena sativa* L., cv. Genziana; O) and triticale (*x triticosecale* Wittm., cv. Vivaciò; T). In total, 16 treatments were evaluated: six pure stands (P1, P2, N, V, O, T), eight binary mixtures (P1T, P1O, P2T, P2O, NT, NO, VT, VO) and two 4-species complex mixtures (P1P2OT, VNOT). A randomised complete block design with four replications was used to arrange plots. Plots were 4 × 3 m, and row spacing was 0.25 m. Sowing rates were 70 germinating seeds m^{-2} for P1, P2 and N, 140 seeds m^{-2} for V, and 280 seeds m^{-2} for O and T, which represent average values in ordinary crops at the site. Seed rates of each component were halved and reduced to one quarter in binary and complex mixtures, respectively. Sowing took place in mid-November each year. Pre-sowing fertilisation was 45 kg ha^{-1} of P_2O_5 to all plots along with nitrogen (30 kg ha^{-1} to cereal monocultures and 15 kg ha^{-1} to the mixtures). At the end of winter, nitrogen fertilisation was repeated with the same modalities. Harvesting was undertaken in late-April, when cereals were at late heading/early milky stage and small green seeds were present in legume pods. Crop DMY, and legume and weed ratios were estimated on 1 m^2 sampling area in the middle of each plot, followed by oven drying of each herbage component at 65 °C for 62 h. In 2014 and 2015, four groups of local sheep farmers (at least five farmers per group) gave a synthetic visual appraisal of the potential value of crops prior to harvesting in each experimental replication for their own use on the basis of a nine-level score, (ranging from 1 = very poor to 5 = excellent, with 0.5 increments). Farmer's scores on each plot were averaged before data analysis. ANOVA was performed using the software Statgraphics Centurion xv, for DMY free of weeds and for weed proportion of all crops using the fixed factor 'crop' and the random factors 'cropping year' and 'block within year'. Mean differences among treatments were separated by Tukey test at 0.05 probability level. ANOVA linear contrasts for DMY, weed ratio and farmers' assessment were carried out for monocultures vs mixtures, legume monocultures vs legume binary mixtures, binary mixtures vs complex mixtures.

Results and discussion

Variation among crops was significant ($P < 0.01$) for DMY among years (Table 1). The highest DMY was achieved on all combinations in 2016. The top-ranking crops for DM yield in 2015 and 2016 were T and O monocultures, while in 2014 T and O had the lowest DMY. In the legumes monocultures, P2 had the greatest DMY (6.3 t ha^{-1}), followed by V and P1 (5.6 t ha^{-1}), while N had the lowest DMY (1.7 t ha^{-1}).

Table 1. Dry matter yields of sown species (sDMY), weeds proportion on total DMY (tDMY), legume ratio on sown tDMY and farmers' visual score of legume-cereal crops (FAss, 2 years-average score).

Variety[1]	sDMY (t ha^{-1})				Weed ratio (on tDMY, t t^{-1})			Legume ratio (on sDMY, t t^{-1})			FarmAss
	2014	2015	2016	3 y average	2014	2015	2016	2014	2015	2016	Score
P2-O	7.2	7.1	9.1	7.8	0.083	0.156	0.090	0.535	0.271	0.029	3.67
T	2.3	8.1	12.3	7.6	0.201	0.098	0.036	-	-	-	3.17
V-O	6.2	7.6	8.8	7.5	0.038	0.066	0.035	0.592	0.360	0.056	4.25
P1-P2-O-T	6	5.6	10.5	7.4	0.054	0.141	0.042	0.728	0.421	0.072	3.75
V-T	6.3	5.2	10.3	7.3	0.043	0.107	0.105	0.716	0.752	0.268	4.11
O	3.8	7.6	10.3	7.2	0.101	0.074	0.012	-	-	-	3.85
P2-T	5.6	6.3	9.1	7.0	0.088	0.151	0.160	0.996	0.515	0.125	3.52
P1-T	5.2	5.4	10.1	6.9	0.185	0.212	0.166	0.628	0.578	0.078	3.81
N-V-O-T	4.2	5.6	10.2	6.7	0.171	0.127	0.056	0.568	0.457	0.117	4.02
P1-O	5.2	6	8.5	6.6	0.069	0.094	0.044	0.646	0.433	0.049	3.6
P2	8.7	6.5	3.7	6.3	0.083	0.195	0.574	-	-	-	3.57
N-O	4.7	4.2	8.5	5.8	0.146	0.143	0.141	0.155	0.186	0.005	3.36
V	5.6	5.9	5.5	5.7	0.01	0.032	0.207	-	-	-	4.15
P1	6.9	6.5	3.4	5.6	0.109	0.182	0.555	-	-	-	4.15
N-T	3.1	3.5	9.3	5.3	0.214	0.274	0.095	0.238	0.261	0.038	2.94
N	1.5	2	1.6	1.7	0.472	0.417	0.726	-	-	-	3.1
mean	5.2	5.8	8.2	6.4	0.129	0.154	0.185	0.574	0.420	0.080	
l.s.d.	2.03	2.09	3.86	2.81	0.235	0.193	0.241	0.235	0.340	0.097	0.53

[1] P1 = semi-dwarf forage pea; P2 = tall size forage pea; N = Narbon vetch; V = common vetch; O = oats; T = triticale.

The ANOVA linear contrasts (not shown) reported a ranking order for legume binary mixtures in which V and P2- based were the best (7.4 t ha^{-1}), followed by P1 mixtures (6.7 t ha^{-1}) and N mixtures (5.5 t ha^{-1}). The DMY of O- and T- based mixtures, on average, was the same (7.0 t ha^{-1}), as well as DMY of peas or vetches-based mixtures (7.4 and 6.6 t ha^{-1}, respectively). A significantly higher DMY of binary mixes vs their monoculture was shown only where N was the component. According to our analysis, complex mixtures showed a slightly higher DMY than binary mixtures, but the difference was not statistically significant. The presence of weeds in crops increased significantly from the first to the third cropping season. The best weed-controlling crops were T and O monocultures, V monoculture and its binary mixtures regardless of the cereal, and peas in mixtures with O. The highest proportion of legumes was recorded in 2014, when the cereals showed low DMY, but in 2015 and 2016 the legume average was reduced. The legume proportion in binary mixtures also differed significantly among years. The highest legume proportion was found in VT, P1T and P2T, followed by complex mixtures. These data indicate that V, P2 and P1 have a strong ability to compete with cereals, while N is poorly competitive. The farmers' score awarded the best productive results in 2015 compared to 2014 (on average 3.8 vs 3.6). The most appreciated traits in the evaluation of the crops were high DMY and easiness of harvesting. This is why the highest scores were attributed to V monoculture and V-based mixtures. Semi-dwarf forage pea monocultures and mixtures were well appreciated mostly as grain rather than forage crops. Tall size forage pea and P2 mixtures, despite their high DMY, were penalised because they were considered difficult to harvest. The scores of the previously mentioned crops did not significantly differ from those of the other crops, except for N monocultures and its binary mixtures and T.

Conclusion

Our experiment over three cropping years showed that P2-O ensures the best levels of forage production across years. However, its main disadvantage compared to V-based crops is its lower relative content of legumes and the worst ability to control weeds as pointed out by the sheep farmer's evaluation. The stakeholders involvement showed to be very useful to address both selection programmes and the proposal of new agronomic solutions.

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Perennial ryegrass ploidy and white clover: how do they affect sward performance?

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Abstract

Increasing herbage DM production and utilisation on-farm improves efficiency and sustainability. The objective of this study was to investigate the effect of perennial ryegrass (*Lolium perenne* L.) ploidy and white clover (*Trifolium repens* L.) inclusion on herbage DM production and grazing efficiency in an intensive animal grazing system with high nitrogen (N) inputs and a high stocking rate (2.75 livestock units (LU) ha^{-1}). The study was a 2 × 2 factorial design, consisting of two perennial ryegrass ploidies (diploid, tetraploid) and two white clover treatments (grass-clover, grass-only). Four sward treatments (tetraploid-only, diploid-only, tetraploid-clover, diploid-clover) were evaluated over a full grazing season at a system scale. Sward measurements were taken at each grazing occasion for three years (2014 - 2016). Tetraploid and grass-clover swards had a lower sward and tiller density leading to lower post-grazing heights, and had a superior nutritive value when compared with diploid and grass-only swards, respectively. White clover inclusion improved herbage DM production and grazing efficiency over a number of grazing seasons; tetraploid and diploid swards maintained similar herbage DM production but varied in sward structural characteristics leading to differences in grazing efficiency.

Keywords: *Trifolium repens* L., *Lolium perenne* L., ploidy, herbage DM production, grazing efficiency, herbage nutritive value

Introduction

Approximately 0.80 of a dairy cow's diet can consist of grazed herbage and conserved forage in Ireland (O'Donovan *et al.*, 2011), and the production and utilisation of increased quantities of this resource can significantly increase the profitability of Irish dairy-farm enterprises (Dillon *et al.*, 2008). Improving grassland management and increasing herbage DM production through the identification of perennial ryegrass (*Lolium perenne* L.; PRG) cultivars suitable for grazing is vital to a sustainable dairy sector (O'Donovan *et al.*, 2011). The inclusion of white clover (*Trifolium repens* L.; WC) in grass-clover (GC) swards can increase herbage growth rates (Frame and Newbould, 1986) and improve herbage nutritive value (Beever *et al.*, 1986). Previous studies into WC use for dairy production systems (Ribeiro Filho *et al.*, 2003; Humphreys *et al.*, 2009) have reported increased milk and herbage DM production. However, the majority of these studies have been at low N levels (< 150 kg N ha^{-1}) and a low stocking rate (< 2 livestock units (LU) ha^{-1}) and are not operating at the N levels and high stocking rates which favour optimum herbage DM production in grass-only (GO) systems. The objective of this study was to examine the effects of PRG ploidy and WC inclusion on herbage DM production, utilisation and nutritive value in an intensive animal grazing system, under high N levels (250 kg N ha^{-1}) and high stocking rates (2.75 LU ha^{-1}) over a number of grazing seasons.

Materials and methods

A farm-systems grazing study (43.6 ha) commenced in 2014 at Teagasc, Clonakilty, Cork, Ireland; 75% of the swards were sown in 2012 and 25% were sown in 2013. The study was a 2 × 2 factorial design; two PRG ploidies (tetraploid and diploid) and two WC treatments (GC, GO) resulting in four sward treatments (tetraploid only, diploid only, tetraploid + clover, diploid + clover). Twenty blocks of four paddocks were created and balanced for location, topography and soil type. Each treatment was randomly assigned in each block and blocks were designed to keep each treatment adjacent to each other to maintain similar grazing management. Total farmlet area for each treatment was 10.9 ha. Each year, 120 spring-calving dairy cows were assigned to one of the four treatments, after calving, based on breed, parity and calving date. All treatments were stocked at 2.75 cows ha^{-1} and grazed in a rotational grazing system. Weekly monitoring of farm grass cover within each treatment was undertaken using a decision support tool, PastureBase Ireland (Hanrahan *et al.*, 2017) to produce a weekly grass wedge during the grazing season. Target post-grazing sward height was 3.5 - 4.0 cm during the first and last rotations and 4.0 - 4.5 cm during the main grazing season. Inorganic N fertiliser was applied at 250 kg N ha^{-1} $year^{-1}$ across all four treatments between mid – January and mid – September. Measurements were taken at each grazing (2014 - 2016) and included herbage DM yield, nutritive value, sward WC proportion, sward and tiller density and post-grazing sward heights. Data were analysed using Mixed Models in SAS (SAS, 2011). Terms included in the model were PRG ploidy, WC inclusion, block, rotation and the PRG ploidy × WC interaction.

Results and discussion

Diploid and tetraploid swards had similar annual herbage DM production (Table 1; $P > 0.1$; average: 16,220 kg DM ha^{-1}). The GC swards produced an additional 1,467 kg DM ha^{-1} compared to GO ($P <$ 0.0001; GC: 16,954 kg DM ha^{-1}; GO: 15,487 kg DM ha^{-1}). Diploid swards were denser than tetraploid swards ($P < 0.001$; + 9 kg DM cm^{-1}) and GO swards were denser than GC swards ($P < 0.05$; + 9 kg DM cm^{-1}). Diploid swards had a greater tiller density than tetraploid swards ($P < 0.001$; + 805 tillers m^{-2}), and the presence of WC reduced tiller density ($P < 0.001$; - 1,379 tillers m^{-2}). Sward density decreased from 338 to 308 kg DM cm^{-1} from 2014 to 2016 ($P < 0.001$) and tiller density decreased from 4,774 tillers m^{-2} to 3,283 tillers m^{-2} from 2015 to 2016 ($P < 0.0001$). Both PRG ploidy ($P = 0.001$) and WC inclusion ($P < 0.001$) had an effect on post-grazing sward height. Grass-clover swards had a lower post-grazing sward height than GO swards (-0.41 cm) and tetraploid swards were grazed 0.15 cm lower than diploid swards. Sward WC proportion decreased from 2014 to 2016 by 0.17 ($P < 0.001$), however, PRG ploidy had no effect on sward WC proportion (Figure 1). Perennial ryegrass ploidy had an effect ($P <$ 0.05) on all herbage nutritive value characteristics with the exception of crude protein (CP) content. Tetraploid swards had greater organic matter digestibility (OMD; $P < 0.01$; +10 g kg^{-1} DM^{-1}) values and lower structural fibre ($P < 0.001$; neutral detergent fibre (NDF): -18 g kg^{-1} DM^{-1}; $P < 0.001$; acid detergent fibre (ADF): -16 g kg^{-1} DM^{-1}) values throughout the grazing season compared to diploid swards. Grass-clover swards had greater OMD ($P < 0.001$; +22 g kg^{-1} DM^{-1}) and lower structural fibres ($P < 0.001$; NDF: -47g kg^{-1} DM^{-1}; $P < 0.001$; ADF: -17 g kg^{-1} DM^{-1}) when compared with GO swards.

Table 1. Comparison of grazing and nutritive value parameters across the grazing season (2014 - 2016).[1]

	Tetraploid only	Diploid only	Tetraploid+ clover	Diploid + clover	PRG ploidy	WC	Year
Herbage produced (kg DM ha^{-1})	15,581	15,392	17,054	16,853	0.05	0.001	0.001
Post-grazing sward height (cm)	4.22	4.43	3.87	3.96	0.001	0.001	0.001
Density (kg DM ha^{-1})	332	338	320	332	0.05	ns	0.001
OMD (g kg^{-1} DM)	760.6	755.0	786.6	772.0	0.01	0.001	0.001
NDF (g kg^{-1} DM)	445.3	463.9	398.5	416.8	0.001	0.001	0.001
CP (g kg^{-1} DM)	197.6	194.4	240.0	233.8	ns	0.001	ns

[1] OMD = organic matter digestibility, NDF = neutral detergent fibre, CP = crude protein, NS = $P > 0.05$.

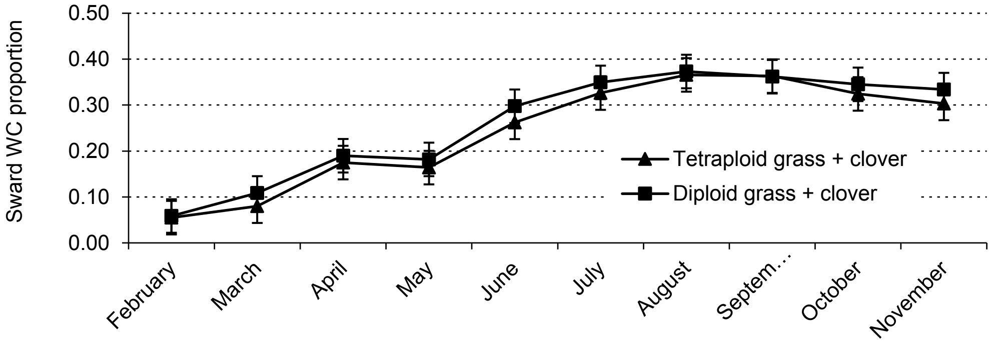

Figure 1. Average sward white clover content across the grazing season for each GC sward (tetraploid + clover (▲) and diploid + clover (■), expressed by mean values; standard error represented by error bars).

Conclusions

In the range of treatments studied, WC inclusion resulted in higher productivity characterised by increased herbage DM production, improved nutritive value and increased utilisation over three grazing seasons. Varying sward composition with PRG ploidy led to improved nutritive value and favourable grazing characteristics (lower post-grazing sward height, reduced tiller density) in tetraploid swards. Overall, this study shows that it is possible to improve productivity by including WC in grass-based production systems at high N levels in association with high stocking rates.

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Improvement silage nutritive and hygienic value using viable lactic acid bacteria inoculant

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Abstract

This paper investigates the effect of adding two different inoculant blends *L.buchneri, L.plantarum, P.acidilactici* (I1) and *L.buchneri, L.plantarum* (I2) to medium wilted perennial ryegrass (*Lolium perenne* L.) on fermentation variables, microbial composition and aerobic stability of the resulting silage according to the DLG (Deutsche Landwirtschafts-Gesellshaft e.V. / internationally acknowledged German Agricultural Society) (90 d after ensiling for Objective 1and 49 d after ensiling for Objective 2) using an *in vitro* set-up with mini silo's. Additives I1 and I2 increased ($P < 0.05$) the dry matter (DM) concentration, crude protein content and decreased ($P < 0.05$) in silo DM losses to a similar extent compared to the untreated control silage in both Objective 1 and Objective 2. Treatments I1 and I2 significantly increased fermentation rate of silages, resulting in a significantly better pH drop 3 d, 90 and 49 d after ensiling compared to the control silages, and produced significantly more lactate. Ammonia-N, alcohols, and butyric acid concentrations in I1 and I2 silages were significantly lower compared to control silage. Inoculant I1 produced more ($P < 0.05$) lactic acid in Objective 1 and Objective 2, and less acetic acid in Objective 1. Treatments significantly reduced the amount of lactate reducing yeasts and of moulds compared to control silage. Inoculant I2 was more effective for improving silage aerobic stability than I1.

Keywords: *Lolium perenne* L., silage, fermentation, aerobic stability

Introduction

To improve the fermentation quality and decrease nutrient loss during ensiling, lactic acid bacteria (LAB) is applied to promote adequate lactic acid production, reduce pH in silage and improve safe feeding of livestock (Kung, 2014; Li *et al.*, 2016). Bacterial inoculants, based on homofermentative LAB are commonly added to silages to improve fermentation and increase dry matter (DM) and energy recovery. Homofermentative LAB are used as inoculants to secure preservation during storage, while heterofermentative LAB are applied to silage to reduce growth of aerobic spoilage strains at feed-out (Milora *et al.*, 2015). Silage inoculants containing heterofermentative LAB, like *Lactobacillus buchneri*, have already been proven to improve aerobic stability by augmented production of acetic acid, which inhibits yeasts (Wambacq *et al.*, 2013). The objective of this trial was to test the effect of two silage LAB blends on fermentation characteristics and aerobic stability of perennial ryegrass (*Lolium perenne* L.) silage according to the DLG (Deutsche Landwirtschafts-Gesellshaft e.V. / internationally acknowledged German Agricultural Society) Guidelines for the testing of silage additives) 90 d (Objective 1 – improving fermentation) and 49 d (Objective 2 – improving aerobic stability) after ensiling using an *in vitro* set-up with mini silo's.

Materials and methods

This study was a randomised block design (2 × 1 × 10 replicates) to analyse the effects of two silage inoculants (*L.buchneri, L.plantarum, P.acidilactici* (I1) and *L.buchneri, L.plantarum* (I2)) on one silage (forage). A negative control (C) was included for each tested product. The first cut form a 2-year old perennial ryegrass (*Lolium perenne* L.) sward was used. Inoculants were applied at an application rate of 300,000 cfu g^{-1} forage. For Objective 1 the mini-silos were fully filled at a density of 1 kg DM 5 l^{-2} (1.89 kg DM at 31.76% DM content) and for Objective 2 mini-silos were fully filled insomuch that the density of the silage in the silos was two thirds of the recommended for Objective 1 (1.27 kg DM at 31.76% DM content). The mini-silos were incubated for a period of 90 d for Objective 1 and for a period of 49 d for Objective 2 at a constant temperature of 20 °C. For Objective 2 the silos were exposed to air stress for one d at d 28 and d 42 after ensiling. In Objective 1 and Objective 2 the stock of yeasts and moulds at the time of silage unloading and the pH value upon completion of the aerobic stability test were determined. Silages were analyzed for DM content, lactic acid and volatile fatty acids (VFA), ethanol, ammonia-N, number of yeasts and moulds and aerobic stability (AS). AS was defined as the number of hours the silage remained stable before rising more than 3 °C above the ambient temperature. Data were analysed as a randomized complete block by using Proc GLM of SAS, version 8.02, 2000 with treatment as a fixed factor. Five replications per treatment were used. Significance was declared at $P < 0.05$.

Results and discussion

The DM (corrected for volatiles) concentrations were 2.9 and 2.7% greater ($P < 0.05$) and DM losses were reduced by 56.6 and 51.0% ($P < 0.05$) for the inoculated I1 and I2 silages compare to uninoculated treatment for Objective 1 (Table1). The increased DM concentration and reduced DM losses in inoculated silages can be related to improved silage fermentation (Li *et al.,* 2016). The I1 inoculant produced significantly more lactate and significantly less acetate than inoculant I2. The pH values 3 days and 90 days after ensiling were significantly lower in I1 silage. However, pH values after completion of aerobic stability were numerically lower in I2 silage. Alcohol concentrations were lower ($P < 0.05$) in I1 than in I2 silage. Yeast and moulds number were significantly ($P < 0.05$) reduced by the application of I1 and I2.

For Objective 2, treatments increased fermentation rate of perennial ryegrass silages, resulting in a better pH drop 3 days and 49 days after ensiling by 0.57 and 0.54 units ($P < 0.05$) (I1) and by 0.36 and 0.44 units ($P < 0.05$) (I2), respectively, when compared with C silage (Table 1). Additives I1 and I2 reduced ($P < 0.05$) ammonia-N concentration by 34.6 and 29.8%, respectively, and alcohols concentration by 48.5 and

Table 1. Means for the fermentation, in-silo losses and microbial variables of perennial ryegrass silages untreated or treated with *L.buchneri, L.plantarum, P.acidilactici* (I1) and *L.buchneri, L.plantarum* (I2) 90 d (Objective 1) and 49 d after ensiling (Objective 2).[1]

	Objective 1				Objective 2			
	C	I1	I2	$LSD_{0.05}$	C	I1	I2	$LSD_{0.05}$
Corr. DM, g kg^{-1} FM	303.28^{b}	312.10^{a}	311.38^{a}	2.899	299.88^{c}	310.04^{a}	306.98^{b}	2.374
Lactic acid, g kg^{-1} DM	41.81^{c}	61.87^{a}	55.83^{b}	5.413	27.30^{b}	54.06^{a}	51.85^{a}	7.067
Acetic acid, g kg^{-1} DM	22.19^{a}	17.24^{c}	20.47^{b}	1.509	19.99^{a}	18.78^{a}	20.30^{a}	1.933
Butyric acid, g kg^{-1} DM	0.93^{a}	0.12^{b}	0.15^{b}	0.385	6.78^{a}	0.92^{b}	0.59^{c}	2.255
Propionic acid g kg^{-1} DM	0.18^{a}	0.19^{a}	0.26^{a}	0.122	0.07^{a}	0.09^{a}	0.08^{a}	0.140
Alcohols, g kg^{-1} DM	7.26^{a}	3.93^{c}	5.07^{b}	0.515	8.16^{a}	4.20^{b}	4.96^{b}	1.190
pH after 3 d.	4.99^{a}	4.32^{c}	4.44^{b}	0.035	5.20^{a}	4.63^{c}	4.84^{b}	0.103
pH after 90 or 49 d.	4.50^{a}	4.11^{c}	4.21^{b}	0.059	4.65^{a}	4.11^{c}	4.21^{b}	0.040
pH after AST	7.74^{a}	4.67^{b}	4.44^{b}	0.433	8.80^{a}	8.28^{b}	8.13^{c}	0.134
Ammonia-N, g kg^{-1} total N	58.02^{a}	36.11^{c}	42.08^{b}	2.850	62.36^{a}	40.79^{b}	43.75^{b}	5.508
DM loss, g kg^{-1} DM	53.04^{a}	23.04^{b}	26.00^{b}	10.003	66.88^{a}	31.34^{c}	40.89^{b}	7.635
Yeast, log cfu g^{-1} FM	3.29^{a}	1.31^{b}	1.12^{b}	0.393	6.13^{a}	3.97^{b}	3.00^{c}	0.551
Moulds, log cfu g^{-1} FM	3.01^{a}	1.22^{b}	1.06^{b}	0.399	4.49^{a}	1.94^{b}	1.51^{c}	0.387
Aerobic stability, hours	79.20^{c}	128.40^{b}	158.40^{a}	12.448	54.00^{b}	87.60^{a}	99.60^{a}	13.999
	$t_{0.05} = 2.179$; error df = 12							

[1] Dry matter, calculated dry matter losses and fermentation parameters are corrected for volatiles; ^{a,b,c} Means with different superscript letters within a row indicate significant differences of $P < 0.05$; I1-I2 – see text in the Materials and methods for explanation of treatments I1-I2.

39.2%, respectively, and did not allow butyric acid formation compared to the uninoculated treatment. Both additive-treated silages had greater ($P < 0.05$) lactic acid content. Treatment I1 reduced ($P < 0.05$) the quantity of lactate reducing yeasts by 35.2% and reduced the quantities ($P < 0.05$) of moulds by 2.3 times compared to control silage. Treatment I2 reduced ($P < 0.05$) the quantity of lactate reducing yeasts two times and reduced the quantities of moulds three times ($P < 0.05$) compared to control silage.

Aerobic stability results of perennial ryegrass silages 49 d and 90 d after ensiling are shown in Figure 1. Compared to the untreated silage, aerobic stability was improved ($P < 0.05$) for I1 and I2 by 64 h (2.7 days) and by 79 h (3.3 days), respectively, (Objective 1), and ($P < 0.05$) for I1 and I2 by 34 h (1.4 days) and by 46 h (1.9 days), respectively (Objective 2).

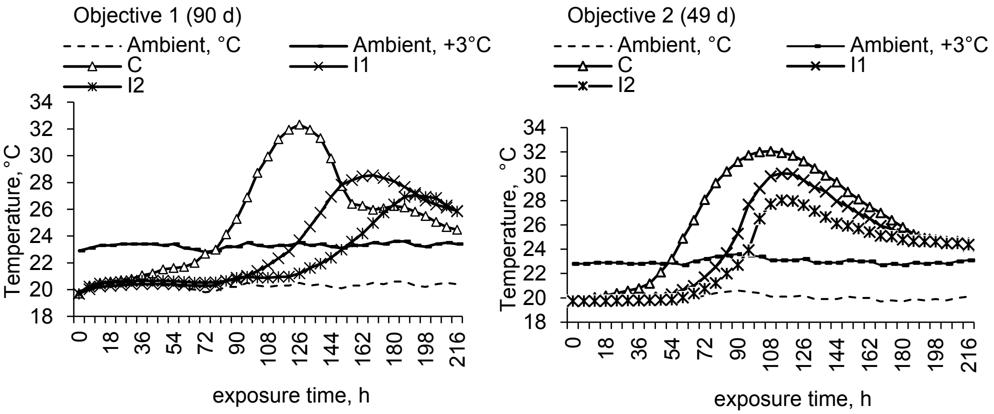

Figure 1. Aerobic stability of the perennial ryegrass silages untreated or treated with (*L.buchneri, L.plantarum, P.acidilactici* (I1) and *L.buchneri, L.plantarum* (I2) 90 d after ensiling (Objective 1) and 49 d after ensiling (Objective 2).

Conclusions

Inoculants I1 and I2 generally had a positive effect on perennial ryegrass silage characteristics (in both Objective 1 and Objective 2) in terms of a greater content of nutrients (DM), a more efficient fermentation, resulting in lower pH, improved fermentation products profile and a lower DM loss. Inoculants were effective in limiting the degradation of protein, lowering the growth of moulds and enhancing silage AS.

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Amazing Grazing; N use efficiency of 60 individual dairy cows under intensive grazing

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Abstract

The Dutch dairy sector aims to improve nitrogen (N) use efficiency (NUE_N) of intensive dairy farms while supporting grazing. To gain insight into the NUE_N of intensive dairy farms, we need insight into the NUE_N at cow level. We performed a 2 × 2 factorial grazing trial with 60 Holstein Friesian cows (7.5 cows ha^{-1}), in which we compared NUE_N of individual cows under two grazing systems, i.e. compartmented continuous grazing (CCG) and strip grazing (SG) and two levels of dietary rumen-degradable protein balance (OEB), i.e. low and high (a difference of 500 g OEB cow^{-1} day^{-1}). Grass and supplementary intakes and faecal and milk outputs were quantified and analysed for N content, during two weeks in July and September 2016. Results showed a higher NUE_N for cows in CCG (39%) compared to cows in SG (36%) in July, due to a lower grass (N) intake in CCG. Low OEB showed a higher NUE_N (40%) compared to high OEB (34%). Our results are key to exploring strategies to improve NUE_N of farms that apply innovative grazing systems.

Keywords: Amazing Grazing, intensive, nitrogen, efficiency, system

Introduction

The Dutch dairy sector aims to improve nitrogen (N) use efficiency (NUE_N) of intensive dairy farms, while supporting grazing. Managing NUE_N is challenging, especially in grazing systems, due to seasonal variation in grass quantity and quality. An imbalance between grass intake and supplementation (concentrates and roughages) at cow level can result in inefficient grassland utilisation or suboptimal feeding. Whereas underfeeding will decrease milk production levels, overfeeding will lead to excessive nutrient excretion. During grazing, the concentrated excreta patches exceed plant requirements locally and increase the risk of nutrient losses to the environment. Improving NUE_N can be extra challenging under intensive grazing as there is knowledge deficit regarding grass intake and utilisation in novel intensive grazing systems. The aim of this study was to analyse the NUE_N of 60 individual dairy cows under intensive grazing, testing two novel grazing systems and two levels of protein intake from supplementary feed.

Materials and methods

A grazing trial was performed with 60 mid-lactation Holstein Friesian cows (7.5 cows ha^{-1}) at Dairy Campus, Leeuwarden, the Netherlands. The grazing trial was set up as a 2 × 2 factorial design, in which we compared NUE_N of two novel intensive grazing systems, i.e. compartmented continuous grazing (CCG) and strip grazing (SG), and two levels of dietary rumen-degradable protein balance (OEB), i.e. low and high (a difference of 500 g OEB cow^{-1} day^{-1}). The novel grazing systems (Holshof *et al.*, 2018) were rotational systems in which the cows were offered fresh grass daily to maximise grass intake and utilisation. The CCG system was set up as a six day rotation system in which the average grass height was kept constant and the size of the plot was sufficient to match grass growth with grass intake. The SG system was set up as a 30 day rotation system in which daily grass allowance matched grass intake. The OEB contrast was created by feeding concentrates with different ingredient formulations, one with sugar beet pulp (- 50

OEB) and one with rapeseed meal (+ 50 OEB). Further details on cow characteristics, treatment groups and diet compositions are provided by Zom *et al.* (2018). The cows were pastured from 09:00 - 16:00 h and supplemented with a mixture of maize silage and soybean meal and concentrates (5.5 kg DM) in the cubicle house.

The NUE_N per cow was determined during two intensive measurement periods of 13 d in July (P1) and September (P2) in 2016. Individual grass and supplementary intakes, and faecal and milk outputs were quantified as described by Zom *et al.* (2018). The N content of these inputs and outputs was analysed. Urinary N excretion was considered to be the balancing item. Nitrogen use efficiency was calculated as: milk N / feed N and, to explain the results, N digestibility was calculated as: (feed N – faeces N) / feed N. The statistical programme GenStat 18 was used for a two-way ANOVA with grazing system and OEB level as factors.

Results and discussion

In P1, NUE_N was higher in CCG (39%) than in SG (36%) ($P = 0.003$), mainly because the N intake via grass was lower in CCG than in SG (Table 1). The higher grass intake in SG compared to CCG confirms our expectations, as SG is expected to ensure a higher constant supply of fresh grass. In P2, however, NUE_N did not differ between CCG and SG ($P = 0.723$), because the lower grass intake in CCG was compensated for by higher OEB content of the grass (84 g kg DM^{-1} in CCG vs 65 g kg DM^{-1} in SG). High OEB resulted in a lower NUE_N (34%) compared to low OEB (40%) ($P < 0.001$; Table 1), despite the higher N output via milk for high OEB (160 g cow^{-1} day^{-1}) compared to low OEB (144 g cow^{-1} day^{-1}).

Table 1. The effects of grazing system and dietary rumen degradable protein balance on the nitrogen (N) use efficiency of 60 individual dairy cows under intensive grazing.

	P[1]	Treatment groups[2]				GS[3]	OEB[4]	GS*OEB[3,4]
		CCG-H	CCG-L	SG-H	SG-L	*P*	*P*	*P*
Total feed (kg DM cow^{-1} day^{-1})	1	19.3	18.3	18.8	18.1	0.249	0.01	0.678
	2	18.9	18.0	18.9	17.5	0.579	0.006	0.518
Total feed N (g cow^{-1} day^{-1})	1	472	354	480	375	0.071	< 0.001	0.424
	2	447	360	454	351	0.924	< 0.001	0.419
Grass (kg DM cow^{-1} day^{-1})	1	4.1	4.2	4.6	4.9	0.014	0.477	0.559
	2	2.8	3.4	3.6	3.8	0.033	0.159	0.547
Grass N (g cow^{-1} day^{-1})	1	140	132	161	166	0.002	0.881	0.44
	2	113	139	128	141	0.395	0.058	0.502
Milk (kg cow^{-1} day^{-1})	1	30.8	25.8	31.0	25.9	0.834	< 0.001	0.937
	2	28.9	25.2	29.4	25.5	0.619	< 0.001	0.903
Milk N (g cow^{-1} day^{-1})	1	170	148	166	144	0.255	< 0.001	0.986
	2	150	144	153	142	0.921	0.081	0.618
Faecal N (g cow^{-1} day^{-1})	1	162	152	146	140	< 0.001	0.023	0.481
	2	136	148	146	131	0.67	0.811	0.054
Urine N (g cow^{-1} day^{-1})	1	140	54	168	91	< 0.001	< 0.001	0.541
	2	159	68	155	78	0.758	< 0.001	0.484
NUE_N[5] (%)	1	36	42	34	39	0.003	< 0.001	0.24
	2	34	40	34	41	0.723	< 0.001	0.817
N digestibility[6] (%)	1	66	57	70	63	< 0.001	< 0.001	0.281
	2	69	58	68	63	0.463	< 0.001	0.179

[1] P = period; 1 = July, 2 = September; [2] CCG = compartmented continuous grazing, SG = strip grazing, H = high rumen degradable protein balance, L = low rumen degradable protein balance; [3] GS= grazing system; [4] OEB = rumen degradable protein balance; [5] NUE_N = nitrogen use efficiency in milk N/ feed N; [6] N digestibility = (feed N – faeces N) / feed N.

Differences in NUE_N between the four treatment groups were influenced by differences in N digestibility of the diet. A high NUE_N was associated with a relatively low N digestibility of the diet, whereas a low NUE_N was associated with a relatively high N digestibility of the diet. This is because a higher N digestibility resulted in a relatively larger share of N excretion via urine than via milk. In P1, N digestibility was higher in SG than in CCG ($P < 0.001$), which can be explained by the relatively higher N intake via grass (Table 1). Period 2 did not show a similar result due to a lower grass N content for SG. Nitrogen digestibility was higher for high OEB than for low OEB ($P < 0.001$), which can be explained by the higher N intake from concentrates in high OEB. Compared to other studies, we found relatively high values for NUE_N (average 37%), and relatively low values for N digestibility (average 64%). Milk N output was relatively low, especially for low OEB (144 g cow^{-1} day^{-1}), but in proportion to the low feed N intake this results in a high NUE_N. The low N digestibility, can be explained by a relatively large share of N excretion via faeces (143 g cow^{-1} day^{-1} for low OEB and 148 g cow^{-1} day^{-1} for high OEB), and a relatively small share of N excretion via urine (73 g cow^{-1} day^{-1} for low OEB and 156 g cow^{-1} day^{-1} for high OEB). The relatively low digestibility and high N excretion in faeces might partly result from our assumption regarding N recovery rate of grass. Van den Pol-Van Dasselaar *et al.* (2006) indicated that the recovery rate of grass supplemented with maize silage might be higher than the one we assumed based on Mayes *et al.* (1986b). Differences in urinary N between the low and high OEB groups might partly be explained by an increasing efficiency in urea-N recycling with a decreasing protein content of the diet (Russell *et al.*, 1992).

Conclusions

Results showed a higher NUE_N in CCG (39%) compared to SG (36%) in P1 due to a lower grass N intake. Low OEB showed a higher NUE_N (40%) compared to high OEB (34%). In general, we found an increase in urinary N excretion, an increase in N digestibility and a decrease in NUE_N with an increase in total N intake. We found a relatively large share of N in faeces and low share of N in urine. This might have implications for the actual local environmental impact of intensive grazing as urine N is the major contributor to nitrate leaching. The results of this study are key to exploring strategies to improve NUE_N of farms that apply innovative grazing systems.

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Effect of soil type, lime and phosphorus fertiliser application on grass yield and quality

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Abstract

High soil fertility levels are essential to maximise grass growth over an extended grazing season. The implementation of sustainable nutrient management practices on grassland farms is critical for maintaining sustainability within grassland systems. The objective of this study was to identify the optimum management of lime and chemical and organic phosphorus (P) fertilisers for grass production across grassland soils representing the main mineral soil types in Ireland. A series of experiments were conducted across pot, microcosm and plot scales to investigate the effects of lime and fertiliser treatments on soil fertility and grass yield and quality. These studies showed a large P lock up potential of different mineral soils in Ireland. On high yielding grassland soils, a positive grass yield response to P fertiliser application across a range of background soil P fertility levels was found. The addition of lime significantly increased soil pH, soil test P and grass P recovery. Targeting slurry applications to low pH soils represented a greater return on P input compared to chemical P. Overall, these studies show that soil specific nutrient advice can be integrated on grassland farms to increase P efficiency and improve the economic and environmental sustainability of grassland farming systems.

Keywords: soil type, lime and phosphorus fertiliser, grass yield

Introduction

An adequate phosphorus (P) supply is required to maintain grassland productivity for intensive grassland farming systems. Phosphorus levels in Irish soils are naturally low and P availability is also strongly related to soil pH status. A recent survey of grassland soils used for agriculture shows that 63% of samples were sub-optimum for pH, highlighting a key factor leading to underperformance of Irish grasslands. The increased adoption of grazing management systems by farmers has been promoted as conferring advantages in terms of profitability and environmental sustainability, however, the accrual of these benefits are dependent on high quantities of grass production over a long growing season. In addition, careful management of these nutrients in fertilisers and organic manure applications on farms is required due to their potential negative effects on aquatic environments, and this is tightly regulated at farm level under the EU Nitrates Directive (S.I. No. 31 of 2014). Previous research conducted at Johnstown Castle has shown large variability in native soil nutrient supply and response to applied fertilisers across different soil types in Ireland (Sheil *et al.,* 2016). Current advice does not account for differences in soil P dynamics and potentially different P supply to grass as affected by soil type and soil pH level. The objectives of this project were to investigate the relationships between soil pH and P fertiliser with soil P availability, grass yield and grass P concentration across different soil types and fertility gradients at multiple scales. To achieve these objectives, a series of studies at various scales, i.e. soil incubations, soil-plant microcosms, and on-farm grass plot trials in four regions across Ireland, were established. These experiments allowed for an in-depth investigation of soil P, herbage P concentration and fertiliser P response on these different soil types in Ireland.

Methods

Soil incubation experiment

Soil was collected from 22 grassland sites (to 10 cm depth) representing a range of agricultural soils in Ireland. On hundred g (dry weight equivalent) of soil was incubated under aerobic conditions at 15 °C and 80% water filled pore space for 12 months. Phosphorus treatments consisted of a control (0 kg P ha^{-1}), dairy cattle slurry and chemical P (100 kg P ha^{-1}) all with and without lime addition (5 t ha^{-1}) and chemical only P treatments (50 and 150 kg P ha^{-1}). After 12 months, these soil and fertiliser incubations were analysed for pH, Morgan's extractable P and K, and Mehlich III P, Al, Fe and Ca. The effects of soil type, pH, soil P fertility and P fertiliser type on soil pH and P availability were investigated.

Grass microcosm studies

For this study, 22 vegetated soil microcosms (30 cm diameter × 40 cm deep) representing a range of mineral soil types were developed and seeded with perennial ryegrass (*Lolium perenne* L.) and left outdoors under one climatic regime at Teagasc, Johnstown Castle, Research Centre. Soil fertility treatments of lime (1.5 t ha^{-1}) and P fertiliser as either dairy slurry (20 kg P ha^{-1}) or chemical P (20 and 40 kg P ha^{-1}) were applied annually to four replicates of each soil type, in addition to an untreated control. SulphaCAN (300 kg N ha^{-1} and 16 kg S ha^{-1}) and Muriate of Potash (375 kg K ha^{-1}) were applied annually in three equal splits post-harvest. Herbage yield and nutrient offtake were determined in four harvests per annum from 2015 to 2017. The effects of soil type, pH, soil P fertility and P fertiliser type and rate on grass yield response and P recovery in grass were investigated.

Long term field plot trials

Four regional grassland trial sites were established, each within the Irish agricultural catchments (Wall *et al*., 2011). These grassland sites had a range in soil P fertility from low to very high. At each experimental site a seven fertiliser treatment (N × P) factorial plot experiment, replicated four times, was established as a randomised complete block design. Treatment plots of 6 × 2 m were sown with a perennial ryegrass mix. The treatments included four rates of N (0, 100, 200, 300 kg ha^{-1} yr^{-1}) applied as SulphaCAN (26.6% N and 5% S) and three rates of P (20, 40, 60 kg ha^{-1} yr^{-1}) applied as triple super phosphate (16% P). Grass was harvested to 4 mm on a monthly basis and DM yield and grass nutrient content determined. Soil sampling was conducted at the start of each year between 2013 and 2017 and used to assess changes in soil pH, soil test P and K levels.

The data generated in these experiments were analysed using ANOVA and stepwise multiple linear regression modelling in SAS 9.4.

Results

The results from the soil incubation experiment indicate that the interaction of soil type with soil pH had a significant effect on soil test P (STP) response to chemical and organic P applications. There was a significant increase in STP from lime applications alone and when in combination with chemical and organic P sources across all sites (Figure 1). There was no significant difference between chemical and organic P treatments when lime was applied; however, organic P had significantly higher STP than chemical P applications (100 kg P ha^{-1}) without lime addition. These results show the large P lock up potential of different mineral soils in Ireland.

Results from the microcosm studies show the large grass DM yield potential of Irish mineral soils. The addition of lime significantly increased soil pH, STP and crop P across all treatment combinations. Soil pH correction prior to P application had a significant effect on maximising P fertiliser use efficiency.

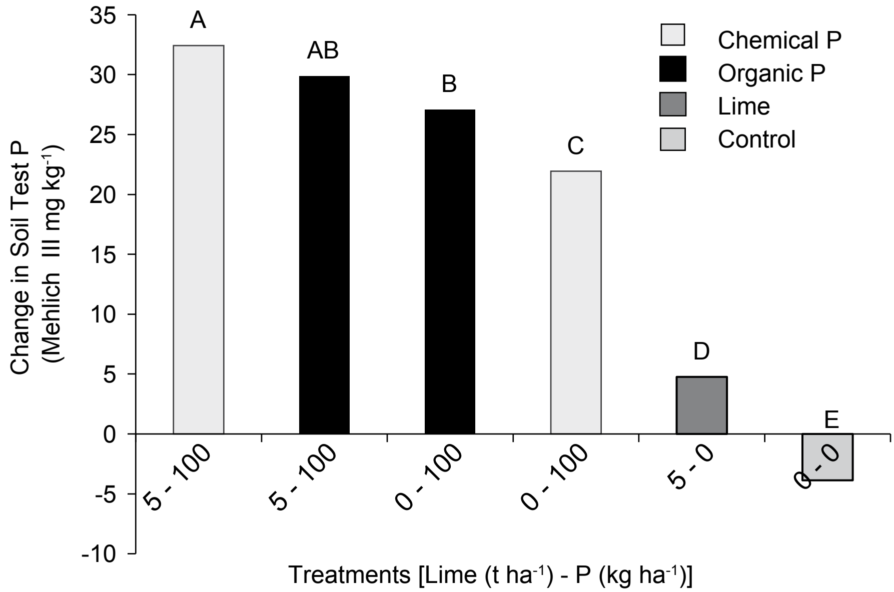

Figure 1. Mean change in soil test phosphorus levels (mg kg^{-1}) in response to applications of lime, chemical phosphorus or organic phosphorus across 22 mineral soil types.

At field plot scale, there were positive grass yield responses to P fertiliser applications at all sites, including those with high STP status. The overall P balances identified ranged from 15 - 43 kg P ha^{-1}yr^{-1}. As expected, high applications of P on low STP soils showed the greatest potential to build STP, however, the rate of STP change was soil specific. High P fertility soils showed the greatest decline in STP with negative P balance and results indicate that a slightly positive P balance was required to maintain STP at optimum levels.

Conclusions

Liming for pH correction plays a pivotal role in regulating soil P availability and fertiliser P use efficiency in grassland systems. Optimising soil pH in combination with STP is necessary to optimise grass yield potential from soil P resources. Targeting slurry applications to low pH soils represented a greater return on P when compared to chemical P. Annual soil nutrient balance (e.g. P inputs – P offtakes) can have more long term effects on soil fertility and grass yield and quality as soil P reserves respond more slowly to fertiliser management, as either drawdown or build-up, over time. These results demonstrate the requirement for soil specific fertiliser recommendations.

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Sustainable fertilisation of natural grasslands

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Abstract

In Hungary most of the grasslands are utilised extensively and the yield is determined by natural conditions. Oversowing, irrigation and mineral fertilisation is prohibited on the majority of grasslands by nature conservation regulations. For this reason steps were taken to increase the productivity of natural grasslands through the application of organic fertilisers. In a field experiment, in Karcag Research Institute, the effect of a biocompost on the sward composition of natural grassland was investigated. This compost meets the requirements of sustainable fertilisation both on Nature2000 areas and Agri-environment Schemes (AES). Four treatments were compared: a control and three compost rates (10 t ha^{-1}, 20 t ha^{-1}, 30 t ha^{-1} fresh weight). Ground cover (GC), GC of different plant groups and GC of individual species measurements were taken in May in each of the three experimental years (2015 - 2017). Results of the experiment presented are GC, GC of different plant groups and of some specific grass species, as well as on interspecific responses among plant groups to biocompost application. Applying compost caused an increase in GC of tall grasses and a reduction of short grasses. Changes in GC of legumes were also experienced.

Keywords: sustainable fertilisation, natural grasslands, Hungary

Introduction

Sustainable grassland management is encouraged through Agri-Environment Schemes (AES) (Stoate *et al*., 2009) throughout Europe. These regulations support sustainable fertilisation of grasslands to maintain the grasslands' ecosystem services. Biocompost is considered a sustainable fertiliser even on grasslands due to its fully organic origin. Some examinations of species richness of grasslands participating in AES found more species on moderately manured grasslands than on unfertilised ones (de Sainte Marie, 2014). Similar results were observed in preliminary field trials in Karcag Research Institute in Hungary. Thus, an experiment was undertaken to investigate the effect of a biocompost on grasslands at the same research institution. As the compost is made of on-farm materials, does not contain artificial substances and does not increase the GC of undesirable plants it can be considered a sustainable method of fertilisation.

Materials and methods

The experiment commenced in 2015 on a natural grassland on solonetz soil type. The sward was rich in species dominated by *Festuca pseudovina* Hack. and *Alopecurus pratensis* L. Treatments were: control and three compost rates (10 t ha^{-1}, 20 t ha^{-1}, 30 t ha^{-1} fresh weight, hereafter referred to as T0, T10, T20, T30, respectively). The experimental was a randomised block design and each plot was 10 × 30 m. Biocompost was applied in February 2015, in October 2015 and in October 2016. Chemical composition of the biocompost is presented in Table 1.

Measurements were undertaken in May and September by visual estimation as per Balázs (1960). Applying this method, three sampling areas (2 × 2 m) were used in each experimental plot, divided into 32 sections to estimate the ground cover (GC) of certain species. As GC was estimated, individual species were grouped as tall grasses ('hay grasses'), short grasses ('grazing type'), legumes and other herbs. Data were analysed using SPSS (ANOVA and correlation analysis). This paper presents the results of three years (2015 - 2017) on sward composition measured before first cut in late May.

Table 1. Main contents of the compost.

	DM	OM	N	P	K	Ca	Mg
percentage by mass (wt%)	60	50	2.5	1.9	5	1.8	0.7

Results and discussion

The application of biocompost reduced the openness of the sward (uncovered area) in the first year. In 2016 and 2017, no open spaces were found in the treatments. The closed sward on T0 treatments was most likely due to good precipitation experienced in springtime (Table 2).

The increase in biocompost rates increased the GC of tall grasses. As a consequence, the GC% of short grasses decreased.

Table 2. GC responses of sward groups to compost treatment.[1]

Year	Treatment	Tall grasses	Short grasses	Legumes	Other	Uncovered
2015	T0	9.77 ± 2.67^{a}	64.06 ± 4.6^{a}	11.72 ± 5.18^{ab}	12.89 ± 0.78^{a}	1.56 ± 1.8^{a}
	T10	18.75 ± 8.07^{ab}	52.34 ± 2.71^{b}	13.28 ± 2.99^{a}	15.23 ± 3.91^{a}	0.39 ± 0.78^{ab}
	T20	24.61 ± 4.84^{b}	49.61 ± 9.23^{bc}	10.94 ± 3.13^{ab}	14.84 ± 5.34^{a}	0.00 b
	T30	40.23 ± 6.8^{c}	40.23 ± 8.69^{c}	7.03 ± 2.99^{b}	12.50 ± 4.23^{a}	0.00 b
2016	T0	18.75 ± 3.38^{a}	46.88 ± 4.42^{a}	17.96 ± 1.56^{a}	16.41 ± 5.78^{a}	0.00
	T10	30.01 ± 5.62^{a}	23.44 ± 6.51^{b}	32.81 ± 7.44^{b}	13.67 ± 3.91^{a}	0.00
	T20	29.69 ± 12.56^{a}	16.8 ± 4.49^{bc}	39.84 ± 8.61^{b}	13.67 ± 3.46^{a}	0.00
	T30	66.8 ± 13.1^{b}	11.72 ± 1.56^{c}	9.38 ± 7.65^{a}	12.11 ± 4.49^{a}	0.00
2017	T0	5.47 ± 1.56^{a}	50.78 ± 10.33^{ab}	11.33 ± 2.34^{a}	32.42 ± 10.7^{a}	0.00
	T10	10.94 ± 1.8^{b}	53.13 ± 12.17^{a}	15.63 ± 16.73^{a}	20.31 ± 7.76^{b}	0.00
	T20	17.19 ± 3.13^{c}	40.23 ± 9.66^{ab}	17.19 ± 11.55^{a}	25.39 ± 5^{ab}	0.00
	T30	35.55 ± 5.32^{d}	37.11 ± 6.8^{b}	7.03 ± 8.22^{a}	20.31 ± 4.6^{b}	0.00

[1] $P < 0.05$.

Table 3. Interspecific reactions to compost treatment in short grasses group.

Year	Treatment	*Festuca rupicola*	*Festuca pseudovina*	*Poa pratensis*
2015	T0	16.85 ± 5.28	79.42 ± 4.82	3.73 ± 1.62
	T10	8.08 ± 4.21	81.29 ± 5.21	10.64 ± 6.37
	T20	9.45 ± 7.89	70.96 ± 10.31	19.59 ± 6.92
	T30	8.61 ± 8.88	66.18 ± 5.86	25.20 ± 5.7
2016	T0	8.14 ± 3.21	89.27 ± 5.23	2.59 ± 3.39
	T10	10.32 ± 7.83	73.02 ± 5.02	16.67 ± 10.73
	T20	6.12 ± 4.13	75.37 ± 20.37	18.51 ± 19.6
	T30	3.57 ± 7.14	48.21 ± 3.57	48.21 ± 3.57
2017	T0	10.21 ± 3.7	85.83 ± 2.24	3.96 ± 1.79
	T10	7.35 ± 2.57	74.32 ± 9-03	18.34 ± 9.26
	T20	0.93 ± 1.85	64.96 ± 11.78	34.12 ± 13.52
	T30	0.0	30.83 ± 13.82	69.17 ± 13.82

The GC % of legumes increased from T0 to T10, and from T10 to T20, but the highest rate of biocompost reduced the GC% in these treatments, most likely due to the repressive effect of tall grasses. There was no significant effect of treatment on the GC of other herbs. *Alopecurus pratensis* L. and *Poa pratensis* L. were able to increase their GC % within their plant group, thus we presume these species have better nutrient response than others. For example, among short grasses, *P. pratensis* increased their GC %, while at the same time the GC % for two local grass species (*Festuca rupicola* and *F. pseudovina*) decreased (Table 3). The correlation analysis showed that these interspecific changes were always significant, and in most cases they were highly significant ($P < 0.01$; Table 4). As yield potential and quality of *P. pratensis* is better than those for *Festuca* species mentioned before, the compost application may increase both yields and quality of herbage produced on grasslands.

Table 4. Correlation between short grass species and treatment.

Year		Correlations			
		F. pseudovina	*P. pratensis*	Treatment	*F. rupicola*
2015	*F. pseudovina*	1	-0.750**	-0.857**	0.539*
	P. pratensis		1	0.800**	-0.572*
	Treatment			1	-0.600*
	F. rupicola				1
2016	*F. pseudovina*	1	-0.726**	-0.880**	0.572*
	P. pratensis		1	0.765**	-0.558*
	Treatment			1	-0.637**
	F. rupicola				1
2017	*F. pseudovina*	1	-0.823**	-0.845**	0.827**
	P. pratensis		1	0.892**	-0.732**
	Treatment			1	-0.807**
	F. rupicola				1

** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed).

Conclusions

Results of the experiment show that a better soil nutrient status due to biocompost application may favour tall grasses. Higher biocompost rates will reduce sward legume content.

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Framework for yield gap analysis in grasslands

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Abstract

Yield gaps estimated for current crop production have received little attention in grassland science. This paper provides a coherent approach for quantifying yield gaps in grasslands, addressing the specific methodological challenges. A preliminary assessment of yield gaps in the Netherlands and the Rogaland region in Norway shows relative yield gaps, i.e. between water limited yields and actual yields, of 24 and 37%, respectively.

Keywords: grassland production, modelling, potential yield, actual yield, yield gap

Introduction

The yield gap between potential and actual crop production is a useful indicator to identify areas for sustainable production increases to meet increasing demand. Until now, yield gaps have mainly been quantified for arable crops (www.yieldgap.org; Van Ittersum *et al*., 2013). The lack of attention for grassland can be attributed to several factors. First, forage from grassland is an internal farm product and not a cash crop. Despite its importance, grassland productivity contributes only indirectly to farm financial performance. Second, the methodological complexity of estimating grassland production may have hindered progress. These scientific challenges and the global importance of grasslands justify research in this direction. The objective of this contribution is to present a coherent approach for quantifying yield gaps in grassland and to conclude with examples for the Netherlands and Norway.

Theoretical production ecology

Potential yield (Y_P) is the yield of a crop cultivar grown without any water and nutrient limitation and the absence of biotic stress. It is determined by radiation, temperature, atmospheric CO_2 and the genetic attributes of a particular crop cultivar. Water limited yield (Y_W) is also affected by precipitation, evapotranspiration, soil type and topography. Nutrient limitations may further restrain crop growth. In the European context, nitrogen (N) limitation due to the Nitrate Directive is very relevant and, therefore, the water and N limited yield (Y_{WN}) is a useful benchmark as well. The actual yield (Y_A) is defined as the on-farm yield. The yield gap (Y_G) under rain-fed conditions is the difference between Y_W and Y_A.

Framework for grassland

Yields (Y_P, Y_W, Y_{WN}, Y_A) may be established by empirical or model-based approaches and need to be quantified for a given time frame and geographical unit. Given the lack of empirical data for some regions, Van Ittersum *et al.* (2013) recommend using crop models to estimate Y_P, Y_W and Y_{WN} for homogenous agro-climatic zones. Still, experimental data of yields under optimal management are needed to calibrate and validate the simulations. Reliable assessment of Y_A requires robust statistical data with sufficient temporal and spatial resolution. Overall, quantifying yield gaps requires a wide variety of data on climate, soils, land use, management and yields. Here, we focus on elements relevant for grasslands. First, a meaningful benchmark should consider function (production, biodiversity), botanical composition (monocultures, mixed swards), ploidy (diploid, tetraploid), variety, heading date (early, late), sward age (newly sown, temporary, permanent), management (cutting, grazing), and harvest stage (continuous grazing, rotational grazing, silage, hay). As it is challenging to acquire spatially explicit data at this level of detail, we propose a tiered system, using the best available data in a specific region. Second, grassland production can be defined at several stages along the chain from aboveground standing biomass to animal intake. Commonly used are gross production (excluding the stubble), net production (excluding harvest losses) and net feed intake (excluding conservation and feeding losses). Third, yields are traditionally expressed in fresh matter, dry matter or organic matter, whereas in livestock systems it may also be relevant to consider the energy or protein value.

The Netherlands

Grasslands are mainly used in intensive dairy farming with high stocking rates and nutrient inputs. In 2016, the total area of 975,000 ha comprised 71% permanent and 25% temporary grasslands, while 4% were natural grasslands. On mineral soils, perennial ryegrass (*Lolium perenne* L.) dominates, whereas on organic soils, species such as rough-stalked meadow grass (*Poa trivialis* L.) are also common. Grasslands are cut all year round, or cut once or twice a year in combination with grazing.

Statistical data on Y_A are available for two to six regions. Between 1990 and 2015, the overall average net DM yield was 9.0 t ha^{-1} year^{-1}. Assuming harvest and grazing losses of 20%, it equates to a gross DM yield of 10.8 t ha^{-1} year^{-1} (Table 1).

Two suitable datasets for empirical assessment of Y_W or Y_{WN} exist. One set comprises 311 experiments, mainly cutting trials with varying N inputs. The greatest DM yields varied from 10 to 20 t ha^{-1} year^{-1}, observed at N inputs of 250 to 870 kg ha^{-1} year^{-1}. The mean maximum DM yield was 14 t ha^{-1} year^{-1}. These values may be considered as estimates of Y_W on swards of varying age. Another set involves 180 cultivar experiments with N inputs similar to those on commercial farms. The maximum DM yield varied from 7.6 to 21.2 t ha^{-1} year^{-1}, with an average of 16.3 t ha^{-1} year^{-1}. These values could be considered as estimates of Y_{WN} for young perennial ryegrass swards with the newest varieties.

The Y_P, Y_W and Y_{WN} were also estimated with the empirical model GRAS2007 (Holshof and Van Den Pol-Van Dasselaar, 2014). Yields were simulated for 25 years for five weather stations and 18 soil types. The average gross Y_P in a combined cutting and grazing system was 15.7 t ha^{-1} year^{-1}. Y_W was 9% lower (Table 1). Reducing the N input by 50% reduced the yields (Y_{WN}) by an additional 10%. This approach results in a provisional estimate of Y_G (Y_W-Y_A) of 3.5 t ha^{-1} year^{-1} or 24% of Yw, of which 43% can be attributed to N limitation (Y_W-Y_{WN}).

Norway

Grasslands are the most important source of forage for ruminant systems. Due to the relatively short growing season (four - eight months) a large proportion of grass is harvested for winter feeding. In 2016, the total area of 650,000 ha comprised 73% temporary and 27% permanent grasslands. In regularly renewed swards timothy (*Phleum pratense* L.) dominates, often with red clover. In areas with mild winter conditions along the southwest coast, perennial ryegrass swards are common. Typically, swards are cut two - three times per year, or four times on the best locations in the south. Pasture intake varies between farms, mainly depending on pasture availability.

Table 1. Modelled estimates of Y_P, Y_W, Y_{WN}, and statistical estimate of Y_A, and the resulting Y_G, all expressed as gross DM yield (t ha^{-1} year^{-1}).

Country (region)	Y_P	Y_W	Y_{WN}	Y_A	Y_G (Y_W-Y_A)
Netherlands	15.7	14.3	12.8	10.8	3.5
Norway (Rogaland)	13.8	12.9	12.3	8.1	4.8

Statistical data on Y_A is available for 18 regions from several decades. Between 2000 and 2016, the overall average net DM yield was 6.2 t ha^{-1} $year^{-1}$. The lowest regional net DM yield (Y_A) was estimated for Finnmark in NW Norway (3.2 t ha^{-1} $year^{-1}$). The greatest net DM yields were observed in Rogaland in SW Norway, of 7.4 t ha^{-1} $year^{-1}$, which is equivalent to a gross DM yield of 8.1 ha^{-1} $year^{-1}$, assuming 10% losses (Table 1).

Several datasets suitable for empirical assessments of Y_W or Y_{WN} are available. Here, we estimate Y_{WN} based on 60 cultivar trials carried out between 1998 and 2013 including the most commonly grown timothy cultivar during recent decades (Grindstad), and using normal farm practice in the area where the trials are carried out. The average gross DM yield was 11.1 t ha^{-1} $year^{-1}$ for low-altitude regions in southern Norway and 9.8 t ha^{-1} $year^{-1}$ for north Norway and high-altitude regions in the south. These values could be considered as regional estimates of Y_{WN} for young timothy swards with the best varieties.

For Rogaland, Y_P, and Y_W for timothy swards were estimated with the process-based model BASGRA (Höglind *et al.*, 2013). A soil type with intermediate water holding capacity (100 mm) was simulated. The simulated overall average Y_P was 13.8 t ha^{-1} $year^{-1}$ (Table 1). Taking account of water limitation (Y_W) reduced yields by 7%. Simulations were not performed for Y_{WN} but, based on empirical data, a 25% reduction in N input reduces yields by an additional 5%. This results in a provisional estimate of Y_G (Y_W-Y_A) of 4.8 t ha^{-1} $year^{-1}$, or 37%, of which nearly 15% can be attributed to N limitation (Y_W-Y_{WN}).

Conclusions

The challenges for yield gap assessment in grasslands were identified and an approach for yield gap estimation was proposed. A preliminary assessment of yield gaps in the Netherlands and the Rogaland region in Norway show a yield gap of 24 and 37% of Yw, respectively.

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Experimental simulation of intensive grazing and other management systems in a low mountain range

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Abstract

Grazing is generally believed to have a lower potential in primary production, both in terms of output per unit of land area and forage yield stability, compared to cut grassland. But even without taking variables of individual farms into account, extreme weather fluctuations may alter this assumption. A randomised field experiment compared different grassland management systems under identical environmental conditions. Treatments included simulated grazing, a silage cut system and a mix of simulated grazing and silage cut systems. The results showed higher crude protein and energy yields for the high frequency simulated grazing treatment than for the four cut treatment. Even higher yields were possible with a treatment in which intensive grazing followed a single cut in spring. Thus, changes in grassland management systems can improve the forage production for dairy farms.

Keywords: grazing, simulation treading, permanent grasslands, yield

Introduction

Feeding dairy cows based on permanent grasslands has a wide range of ecological benefits (Eisler *et al.*, 2014). System comparisons in the low mountain ranges of Germany showed that locally adapted grazing management can perform better compared to many indoor production systems (Lütke Entrup *et al.*, 2016). This was often the case if large amounts of expensive supplementary feed had to be imported into the farm. Pastures can produce high quality fodder for ruminant nutrition at very low cost. During grazing, plant-animal interactions often initiate an increase in the nutritive value. Energy and crude protein contents can increase in pasture plants which are kept under permanent grazing pressure in low height swards (Loaiza *et al.*, 2016). To allow the comparison of primary production in different grassland management systems, a randomised experiment was designed, which includes the simulation of different grazing systems.

Materials and methods

At the grassland research station in western Germany (410 m above sea level), an experiment was established in 2011 in the form of a partially randomised block design. The primary production of plots (1.25 × 8 m) seeded with a standard mixture GII (47% *Lolium perenne* L. varieties, 20% *Festuca pratensis* Hudson, 17% *Phleum pratense* L., 10% *Poa pratensis* L., and 6% *Trifolium repens* L.) was compared after the implementation of the treatments. The four management treatments were conventional continuous simulated grazing (CCG) at four dates, continuous intensive rotational simulated grazing (CIG), starting in early spring, intensive simulated grazing preceded by one silage cut (SIG) and four silage cuts without any simulated grazing (SCM). Cutting was undertaken with a Haldrup F-55 (cutting height 5 cm). A lawnmower tractor (John Deere X155R) was used to simulate the intensive grazing of the complete plots. This way the sward was homogeneously cut (4 cm), as soon as the sward height (7 - 10 cm) and environmental conditions allowed it. Following each mowing, trampling by cows was simulated with a tractor-pulled compaction roller (550 kg) on which iron replicas of bovine claws were welded. All treatments received the same fertilisation level (230 kg nitrogen (N) ha^{-1} $year^{-1}$, 60 kg N ha^{-1} in mineral form). Since 2014, the simulated grazing treatments received randomly distributed spots of biogas slurry (1.5 l each) to simulate the faecal output of grazing cows. The N amounts for the slurry spots were calculated according to the stocking rates recommended by a grazing calendar (Berendonk and Verhoeven, 2014). With the exception of CIG all treatments received 70 kg N ha^{-1} in spring. After silage cuts slurry was applied uniformly onto the plots at a rate of 50 kg N ha^{-1} twice. For each plot the harvest was weighed and a sample of approximately 500 g dried at 60 °C for 24 h. Nutritional contents were determined by an analysis with near-infrared spectroscopy (NIRS™ 5000, Foss). Statistical analysis was performed with Excel 2010 and R (Version 3.01.). The data were compared via Student's t-tests. Non-homogeneous variances accompanied the treatments.

Results and discussion

Generally the net energy lactation (NEL) and crude protein (CP) contents of the CIG and SIG treatments were higher than those in the herbage from CCG and SCM (Figure 1). This could be explained by increased white clover contents within the CIG and SIG plots. No difference was found between these treatments after June. During drought events CP- or NEL-contents of CIG did not differ significantly from SCM.

Comparisons showed that the yields of CIG and SIG were more constant (Table 1), despite contrasting climate conditions. In 2015, early flowering was common for the treatments CCG and SCM. This limited their vegetative growth. Energy and protein yields were significantly higher for CIG and SIG, except in 2013.

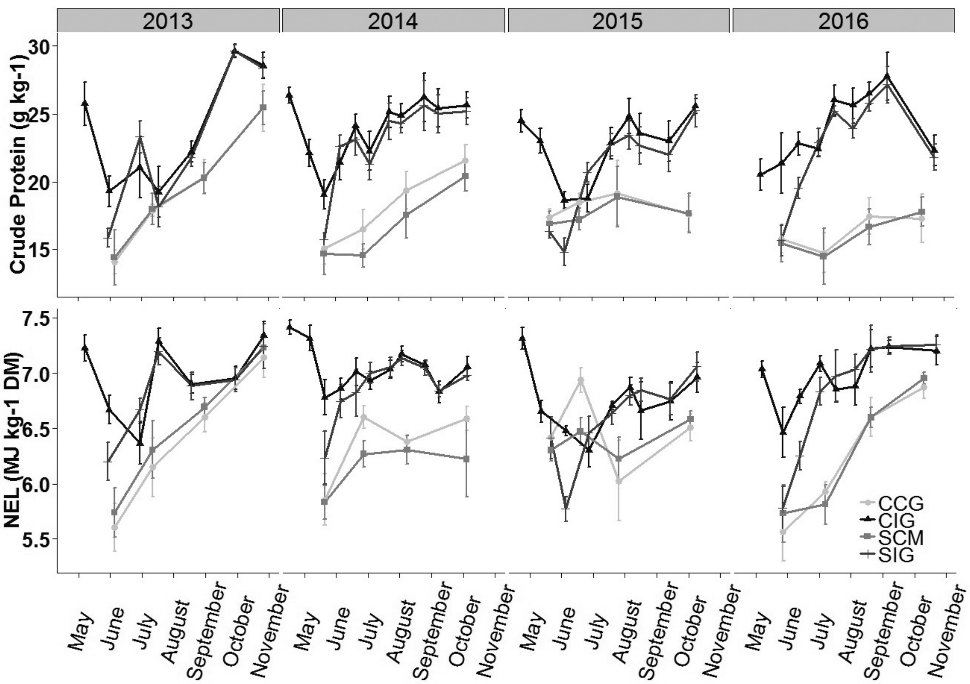

Figure 1. Herbage crude protein and net energy lactation (NEL) contents for the management treatments at each cut or simulation of grazing. Error bars show the confidence intervals for the data distributions (at 95%, n = 6).

Table 1. Means (n = 6) and standard deviations (s.d.) for the dry matter (DM), crude protein (CP) and net energy lactation (NEL) yields for each single year and as a mean for all four years. Letters indicate significant differences ($P < 0.05$) according to pairwise t-tests.

Year	Treatments[1]	DM (kg ha^{-1})		CP (kg ha^{-1})		NEL (GJ ha^{-1})	
		mean	s. d.	mean	s. d.	mean	s.d.
2013	CCG	9,531^{a}	555	1,586^{a}	89	56.2^{a}	4.03
	CIG	6,515^{c}	689	1,506^{a}	177	43.9^{c}	4.84
	SCM	9,820^{a}	836	1,660^{a}	125	59.1^{a}	6.06
	SIG	7,903^{b}	869	1,541^{a}	123	50.6^{ac}	5.51
2014	CCG	8,216^{ab}	709	1,390^{bc}	210	50.0^{b}	5.06
	CIG	7,858^{b}	368	1,943^{a}	309	57.0^{a}	7.17
	SCM	8,521^{ab}	970	1,365^{c}	235	50.6^{b}	5.58
	SIG	9,153^{a}	542	1,830^{a}	165	59.6^{a}	2.70
2015	CCG	6,581^{c}	396	1,172^{b}	85	41.1^{b}	2.66
	CIG	7,678^{b}	597	1,726^{a}	126	49.6^{a}	3.57
	SCM	6,384^{c}	369	1,115^{b}	87	40.1^{b}	2.45
	SIG	8,560^{a}	713	1,611^{a}	159	54.0^{a}	4.45
2016	CCG	8,519^{a}	1,379	1,367^{b}	294	50.2^{c}	8.41
	CIG	9,110^{a}	955	2,083^{a}	251	61.7^{a}	6.51
	SCM	8,692^{a}	1,037	1,359^{b}	237	51.8^{ab}	5.78
	SIG	9,801^{a}	574	1,918^{a}	171	60.9^{a}	3.76
all	CCG	8,212^{ab}	1,340	1,379^{b}	233	49.4^{b}	7.49
	CIG	7,790^{b}	1,137	1,814^{a}	308	53.1^{ab}	8.75
	SCM	8,354^{ab}	1,493	1,375^{b}	261	50.4^{b}	8.44
	SIG	8,854^{a}	962	1,725^{a}	214	56.3^{a}	5.81

[1] CCG = Conventional continuous simulated grazing, CIG = continuous intensive simulated grazing, SCM = silage cuts without any simulated grazing, SIG = silage cut in spring followed by intensive simulated grazing.

Conclusions

The treatments with the simulation of intensive grazing were able to outperform the other treatments in crude protein yields during some years. If the following years affirm these findings, it seems reasonable for advisers and farmers to include grazing into their practices.

Acknowledgements

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Evaluation of the Cornell Net Carbohydrate and Protein System version 7.0 for pasture-based systems

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Abstract

The use of nutritional models in pasture-based systems is limited. Conflicting reports surrounding constraints to more efficient milk production from such systems suggests a need for application of models to integrate animal nutrient requirements and dietary supply. One such model is the Cornell Net Carbohydrate and Protein System (CNCPS), which is used to formulate the rations of millions of cattle around the world every day. Therefore, our objective was to evaluate the ability of the CNCPS version 7.0 to predict milk yield from the supply of metabolisable energy (ME) and metabolisable protein (MP) in pasture-based systems. A data set was compiled consisting of 49 dietary treatment means from nine controlled pasture-based studies. Simulation results demonstrated the capability of CNCPS v7.0 to predict ME or MP allowable-milk, and when evaluated on the basis of first limiting nutrients, ME supply was first limiting in 94% of the evaluations with coefficient of determination (R^2) = 0.67. Further improvement of the predictive ability of the model when simulating high quality pasture diets could be achieved through more in-depth feed chemistry analysis and through investigation of *in vivo* variables, such as forage passage rate and microbial interactions, especially protozoa growth and turnover.

Keywords: dairy cow, milk production, pasture, CNCPS, nutritional models

Introduction

In order to consistently and predictably increase milk solids production from pasture, an understanding of the energy and amino acids supply to the animal and their subsequent metabolism is required. The Cornell Net Carbohydrate and Protein System (CNCPS) is a mathematical model designed to evaluate the nutrient requirements of cattle over a wide range of environmental, dietary, management and production situations (Van Amburgh *et al.*, 2015). The model also uses estimations of carbohydrate and protein degradation and passage rates to predict the extent of ruminal fermentation, microbial growth and the absorption of metabolisable energy (ME) and metabolisable protein (MP) throughout the gastrointestinal tract (GIT). In the most recent update, v7.0 (Higgs and Van Amburgh, 2016), the entire GIT model has been rebuilt, allowing the CNCPS to advance from a static to a more dynamic and mechanistic model. New capability, involving fractionation of pools and degradation rates for nitrogen and neutral detergent fibre (aNDFom), has also been included (Ross, 2013; Raffernato, 2011). This new structure has the ability to model new GIT degradation and passage properties whilst accounting for growth of bacteria and protozoa. Nutritional models help determine the animal's nutrient requirement demands, which change across physiological stages, while also quantifying the supply of nutrients, which is highly variable from pasture-based diets. Therefore, application of the CNCPS has the potential to help quantify the nutrient(s) first limiting production output and feed conversion efficiency.

Materials and methods

A data set was compiled to evaluate the ability of the CNCPS model to predict milk yield from the supply of ME and MP. Lactation trials, undertaken between 2010 and 2017, were used, with cows in different stages of lactation (early, mid, and late). In total, nine pasture-based experimental studies were selected, with 49 treatment means evaluated. The data set consisted of a range of supplements and pasture inclusion levels. Criteria for inclusion required each study to report (a) a description of the ingredients and chemical analysis of the ration fed for each treatment, (b) measured DM intake and (c) milk yield and milk composition for each treatment. Animal information required to run a simulation in the CNCPS included a description of environment, stage of lactation, stage of pregnancy, body weight (BW), body condition score (BCS) and their change over the period studied. For the majority of studies, limited information was presented on the chemical composition of the diets. In this situation, information reported by the study was used and uncertain values were matched, based on crude protein (CP) and aNDFom, to the closest perennial ryegrass variety in the CNCPS feed library. Table 1 describes the experimental data used to create the evaluation data set.

Results and discussion

Outputs from the model are shown in Table 1. Both MP (g day^{-1}) and ME (Mcals day^{-1}) supply are the main output variables. Metabolisable protein is differentiated into the amount of MP from microbial supply with the remainder coming from either feed protein that escaped ruminal degradation or from endogenous material. In terms of ME supply, the model allows identification of not only how much substrate is degraded and utilised but also in which GIT compartment it occurs e.g. aNDFom digestion is proportioned between rumen (73%) and post-rumen digestion (5%; Table 1). These variables help determine a model-predicted allowable milk yield according to the first-limiting nutrient (MP or ME). In our evaluation, model-predicted milk yield was regressed on the observed milk yield and results demonstrated the capability of CNCPS v7.0 to predict the first-limiting nutrient with coefficient of determination (R^2) = 0.67 with a slope of 0.84 and intercept of 3.57 for the studies included in this data set (Figure 1).

In 94% of model simulations, ME supply was first limiting milk production. This correlates with the reported feed chemistry, since the diets evaluated typically contained high levels of CP and aNDFom, with low non-structural carbohydrate inclusion. While prediction capability is not as precise and

Table1. Description of the production data input and model output for the evaluation data set.

Item	Mean	SD	Minimum	Maximum
Diet composition, % of DM				
Crude protein	18.9	2.5	13.8	25.4
Neutral detergent fibre (aNDFom)	34.7	6.0	25.5	51.6
Sugar	9.9	2.0	6.5	13.6
Starch	3.8	4.1	0.1	18.0
Forage inclusion	87.7	14.3	52.2	100
Animal inputs				
Current body weight, kg	511	23	434	576
Body condition score, 1-5 scale	2.8	0.2	2.5	3.6
DM intake, kg day^{-1}	17.4	2.1	13.6	21.2
Milk yield, kg day^{-1}	23.5	5.1	12.8	31.9
Milk true protein, %	3.3	0.2	3.0	3.8
Milk fat, %	4.2	0.8	3.4	7.7
Model outputs				
Metabolisable protein (MP) supply, g day^{-1}	2,045	322	1,470	2,804
Microbial protein, % of MP	68	6	43	77
Metabolisable energy supply, Mcals day^{-1}	44.9	5.5	34.0	56.2
aNDFom intake, g day^{-1}	6,000	1,115	4,300	8,900
Rumen degraded, % aNDFom	73	6	56	82
Total tract degraded, % aNDFom	78	6	62	85

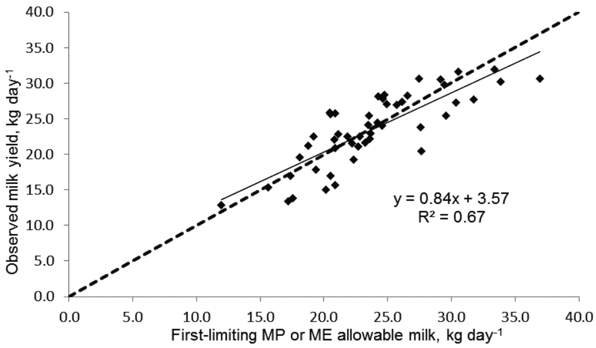

Figure 1. Observed versus Cornell Net Carbohydrate and Protein System v7.0 predictions for first-limiting MP or ME allowable milk.

accurate as previous evaluation of CNCPS v6.5 for confinement systems (Van Amburgh *et al.*, 2015), it is important to consider the limitations of this data set for evaluation purposes. For accurate prediction capability, it is essential that the refined inputs required for model simulation are available. In this evaluation, it was required to make a considerable amount of assumptions surrounding the diet feed chemistry. Development is required to both increase the size and range of the CNCPS feed library for pasture-based systems to more accurately quantify nutrient supply. Additionally, investigation into variables such as passage rates, post-ruminal flow of nutrients and microbial growth may help increase the precision and accuracy of v7.0 for pasture-based systems.

Conclusions

With the data set and assumptions used in this evaluation, the CNCPS v7.0 has an acceptable predictive capability for milk production. This analysis also suggests that generally, ME is the nutrient limiting milk production under the conditions evaluated here. One of the limitations for better predictive ability could have potentially been due to the restricted feed chemistry available, compared to what the model requires. That said, this evaluation indicates the opportunity to refine nutrient supply to the animal under pasture conditions.

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Impact of pre-cutting herbage mass on cow performance and sward utilisation in zero-grazing systems

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Abstract

Zero-grazing is a management technique which is gaining interest on dairy farms in north-west Europe. Limited evidence exists as to the impact of pre-cutting herbage mass on grass utilisation and dairy cow performance under zero-grazing management practices. This study compared the performance of cows managed within a conventional grazing system, with housed cows offered fresh grass cut by zero grazing technology. In a 15-week continuous design experiment, 63 spring-calving Holstein Friesian dairy cows were allocated to one of three grassland management strategies: (1) full-time grazing, (2) housed and fed zero-grazed grass from low herbage mass swards, or (3) housed and fed zero-grazed grass from high herbage mass swards. All treatments were offered concentrate at a rate of 6.5 kg cow^{-1} day^{-1}. Herbage utilisation, animal performance and animal behaviour were measured. Zero-grazing improved total grassland utilisation by 23% compared to full-time grazing ($P < 0.001$). Whilst zero-grazing low herbage mass swards resulted in comparable animal performance to grazing, high herbage mass swards resulted in a 0.26 kg cow^{-1} day^{-1} reduction in milk fat + protein yield. Consequently, farmers operating zero-grazing regimes should maintain pre-cutting herbage masses below 4,000 kg DM ha^{-1} above ground level to optimise sward utilisation and animal performance.

Keywords: zero-grazing, perennial ryegrass, dairy, milk production, grass utilisation

Introduction

Well-managed forages remain among the most cost-effective feedstuffs on dairy farms in the United Kingdom (UK; Kingshay, 2015). With increased global demand for, and fluctuations in both the availability and cost of imported feedstuffs, efficient forage utilisation has been identified as a key driver of profitability on UK dairy farms. The use of grazed grass for dairy cows can result in lower-cost feeding systems (Peyraud and Delaby, 2001), however, research has shown that the supply of fresh herbage alone is insufficient to support optimal dry matter intake (DMI) and, consequently, milk production in high yielding cows (Kolver and Muller, 1998). Although grazing strategies such as increasing pasture allowance can encourage higher levels of DMI (Bargo *et al.*, 2002), low pasture utilisation reduces both forage quality and cost-effectiveness of the feeding system. Consequently, strategies that encourage high pasture utilisation whilst maintaining grass DMI are required to maximise the use of fresh herbage in dairy cow feeding systems.

Novel strategies such as zero-grazing (ZG) seeking to both improve sward utilisation and lower dietary costs of dairy cows are gaining considerable interest on UK dairy farms. However, relatively little is known about the impact of ZG on cow performance, grassland utilisation or economic performance. This study sought to compare grassland utilisation and the performance of lactating dairy cows under three differing grassland management strategies: (1) full-time grazing, (2) housed and fed ZG grass from low herbage mass swards, or (3) housed and fed ZG grass from high herbage mass swards.

Materials and methods

The 15 week study was conducted during summer 2017 at the Agri-Food and Bioscience Institute (AFBI) research farm, Hillsborough, Northern Ireland (54°27'N; 06°04'W). Sixty three Holstein-Friesian dairy cows were allocated to one of three grassland management strategies: (1) full-time grazing, (G) (2) housed and fed ZG grass from low herbage mass swards (ZGL), or (3) housed and fed ZG grass from high herbage mass swards (ZGH). Treatment groups were balanced for calving date, pre-experimental milk yield, milk fat and protein concentration, live weight, parity and genetic merit. Target pre-grazing herbage mass for the G and ZGL treatments was 3,200 to 3,600 kg DM ha^{-1} above ground level, and 4,200 to 4,600 kg DM ha^{-1} above ground level for the ZGH treatment. Eighteen hectares of established perennial ryegrass (*Lolium perenne* L.) were subdivided into 1 ha treatment plots, allocated randomly within six blocks. Grass was managed in a rotational cutting/grazing cycle with fresh herbage allocated daily. Grass for both ZG treatments was harvested daily at 9 am via specialised ZG machinery (GrassTech, Ireland). Target post-grazing cover was 1,800 kg DM ha^{-1}, with grazed areas topped to reach target residual as required. All treatments were supplemented with a grazing concentrate at an average rate of 6.5 kg cow^{-1} day^{-1}. Individual daily milk yield, daily live weight and weekly milk composition were recorded. Step count and lying behaviour was recorded via leg mounted activity sensors (IceRobotics Ltd., Scotland). Grass intake data was determined using automated feed bins (Biocontrol, Norway) for ZGL and ZGH treatments, and herbage offtake for G treatment cows. Pre- and post-grazing herbage mass was determined twice weekly with a cutting bar (Agria, Denmark) and daily using a rising plate meter (Jenquip, New Zealand). Herbage compositional quality was determined twice weekly via near infrared spectroscopy (Foss, Denmark). Total herbage utilisation was determined by measuring consumed and available herbage both in-field and at feed out. Data was analysed using ANOVA in Genstat 16.2 (VSN International Ltd, 2013). Animal performance and behaviour data was analysed by repeated measures (ReML) using an antedependence order 1 model. Herbage data was analysed as a linear mixed model (ReML).

Results and discussion

The higher pre-grazing herbage mass exhibited by the ZGH treatment (4,772 kg DM ha^{-1}) was associated with a significant reduction in grass quality when compared with the G and ZGL treatments (Table 1).

As expected herbage utilisation was significantly higher from the ZG treatments compared with G ($P < 0.001$). However, the ZGH treatment exhibited a longer rotation length and slower re-growth, owing to stage of maturity at cutting, compared with the G and ZGL treatment. This resulted in the ZGH

Table 1. Observed herbage utilisation and compositional quality for each of the three grassland management strategies.[1,2]

	G	ZGL	ZGH	sed	*P*-value
Pre-grazing herbage mass (kg DM ha^{-1})	3,612^a	3,666^a	4,772^b	125.8	< 0.001
Post-grazing herbage mass (kg DM ha^{-1})	2,064^b	1,560^a	1,620^a	52.8	< 0.001
Total herbage utilisation (%)	72.2^a	91.9^b	86.2^b	2.38	< 0.001
Rotation length (days)	25.4^a	25.9^a	46.1^b	1.67	< 0.001
Herbage composition (g kg^{-1} DM)					
Dry matter	15.2	14.7	15.2	0.73	ns
Nitrogen	4.1	4.1	3.9	0.21	ns
Acid detergent fibre	29.5^a	30.2^{ab}	31.3^b	0.56	0.009
Metabolisable energy	11.2^b	11.1^b	10.9^a	0.10	0.009

[1] G = Grazing, ZGL = Zero-grazing, low herbage mass sward, ZGH = Zero-grazing high herbage mass sward, sed = standard error of the difference.

[2] Superscripts denote significant differences between treatments.

exhibiting the lowest stocking rate (4.3 cows ha^{-1}) compared to the G and ZGL treatments (4.9 and 5.0 cows ha^{-1}, respectively).

Animal behaviour was significantly influenced by treatment, with ZGL and ZGH cows exhibiting an additional lying time of 2.0 and 2.2 hours day^{-1}, respectively compared to G (P < 0.001, Table 2). In addition, G cows displayed a 239 and 226% increase in step count compared to the ZGL and ZGH treatments, respectively reflecting the extra energy expenditure associated with grazing. However despite this additional energy expenditure, milk yield was greatest for the G treatment and milk fat + protein yield was comparable to ZGL cows (Table 2). In contrast, both milk yield and milk fat + protein yield were significantly lower for the ZGH treatment, a difference most likely attributable to the lower herbage quality and herbage DMI (12.7 kg DM cow^{-1} d^{-1}) observed with the ZGH treatment relative to G or ZGL (14.8 kg and 13.2 kg DM cow^{-1} d^{-1}, respectively).

Table 2. Impact of grass management strategy on the performance and behaviour of lactating dairy cows over a 15 week period.[1,2]

	G	ZGL	ZGH	sed	*P*-value
Milk yield (kg cow^{-1} day^{-1})	27.0^{c}	25.5^{b}	23.7^{a}	0.66	0.001
Milk fat (g kg^{-1})	40.7^{a}	44.3^{b}	43.7^{b}	1.00	< 0.001
Milk protein (g kg^{-1})	35.0^{b}	34.5^{ab}	33.8^{a}	0.45	0.041
Milk fat + protein yield (kg cow^{-1} day^{-1})	2.06^{b}	1.99^{b}	1.80^{a}	0.047	< 0.001
Lying time (minutes cow^{-1} day^{-1})	597^{a}	716^{b}	728^{b}	20.7	< 0.001
Step count (steps cow^{-1} day^{-1})	10,134^{b}	4,227^{a}	4,485^{a}	261.8	< 0.001

[1] G = Grazing, ZGL = Zero-grazing, low herbage mass sward, ZGH = Zero-grazing high herbage mass sward, sed = standard error of the difference.

[2] Superscripts denote significant differences between treatments.

Conclusions

Whilst ZG offers the potential to achieve high levels of in-field grass utilisation, feeding high herbage mass swards negatively affects dairy cow performance. Consequently, farmers should seek to maintain pre-cutting herbage masses below 4,000 kg DM ha^{-1} to optimise sward utilisation and animal performance under ZG management.

Acknowledgements

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Production and botanical composition of leys in a long-term cropping system experiment in northern Sweden

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Abstract

A long-term experiment was established at three locations in northern Sweden in the late 1950's to examine the production and environmental effects of cropping systems with increasing intensification. This included leys from one to five years in length. Previous reports for this experiment have shown an inverse relationship with loss of carbon and length of ley. This report focuses on the ley component of the systems. The variability in ley yield between seasons was considerably greater than the variability between different treatments, with no significant increasing or decreasing trend over time. This suggests that ley yield is not influenced by the long term cropping system. Clover dominated biomass in the first two years but became a minor component of leys in the third and subsequent years in cropping systems A and B. The results highlight the stabilising effect of leys in cropping systems.

Keywords: crop rotation, forage crop, legume, ley

Introduction

Long-term experiments serve as important resources to investigate management strategies on system outcomes (e.g. crop yield, soil chemical, biological and physical properties). During the second half of the 20th century, farming activities became increasingly specialised in Sweden, leading to the separation of cropping farms and livestock farms. Concern rose as to how this specialisation would influence soil properties and crop yields (Bergkvist and Öborn, 2011). A cropping system experiment was initiated in the 1950's in northern Sweden and is one of the oldest of SLU's long-term experiments. The experiment included four cropping systems, which differed in the number of years of leys in a six-year rotation. Analysis of results from the experiment has so far focused on impacts on the soil. For example, cropping systems with three or five years of ley in the rotation resulted in lower soil bulk density and greater soil carbon than cropping systems with one or two years of ley (Ericson, 1994; Jarvis *et al*., 2017). The objective of this paper was to assess the long-term effects of the different cropping system treatments on the yield and composition of the ley phase.

Materials and methods

A cropping system experiment was initiated at three sites in the 1950's in northern Sweden. This paper only details the results from the site at Offer (63.14 N, 17.75 E), established in 1956. There were four experimental treatments (A, B, C and D) representing different six-year cropping systems with increasing intensity of annual cropping. A was a livestock-focused system, with five years of ley and one year of barley (*Hordeum vulgare* L.), with ley under-sown. B was also focused on livestock production and included a typical length ley (three years) with three years of annual fodder crops. C was balanced between crop and livestock production, with a shorter than normal ley (two years) and four years of annual crops (including cereals, grain legumes and potatoes). D was a completely annual cropping system, with one year of ley cultivated as a green manure, thus the results are not included in this study. All six phases of each cropping system were present each year and there were two replicates per site. Ley species used were red clover (*Trifolium pratense* L.), timothy (*Phleum pratense* L.) and meadow fescue (*Festuca pratensis* Huds.) Leys were initially sown under barley and harvested two times per year. A more detailed description of the experimental design and agronomic management is in Zhou *et al*. (2018). The data used for the analysis are from cropping systems A, B and C, from years 1964 to 2008. Cropping system A is the only treatment with fourth and fifth year leys. All significant effects were at the $P < 0.05$ level.

Results and discussion

For first year leys, the median yields and yield distributions were similar for the three cropping treatments (Figure 1). The variability between years was greater than the variability between treatments. For year two and three leys, there was no significant difference between median yields for treatments A and B. Although it appears in Figure 1 that there are lower yields in fourth and fifth years, there was no significant effect, likely due to the variability between years.

Red clover content in the first and second year leys was significantly higher than in the third, fourth or fifth year (Figure 2). In the first and second year cropping system C tended to have a greater clover content than cropping system A or B. The higher red clover content for cropping systems with a greater proportion of annual cropping may be due to the reduced incidence of diseases. By year three the clover content of the ley had declined to approximately 10% of DM and clover was an insignificant component. Clover content of the second harvest was significantly higher than for the first harvest for ley years one to three (Figure 3), consistent with the common perception of red clover botanical composition in Swedish leys.

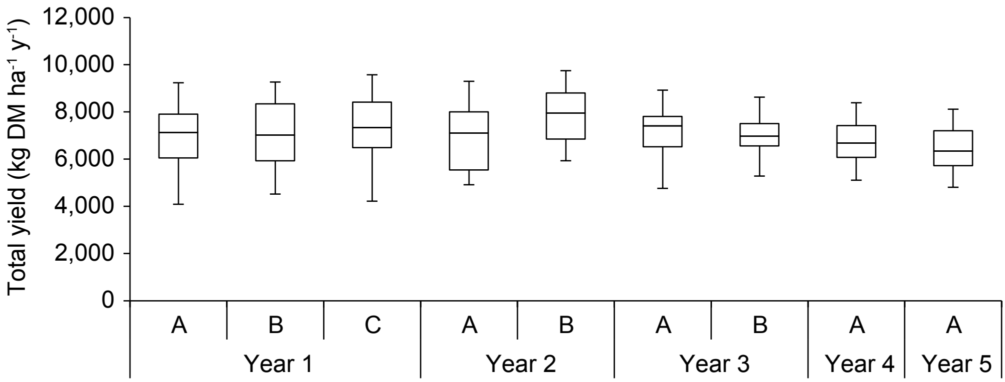

Figure 1. Boxplot of first to fifth year ley yields, in cropping systems A, B and C. The box and whiskers represent the 5th, 25th, 50th, 75th and 95th percentiles.

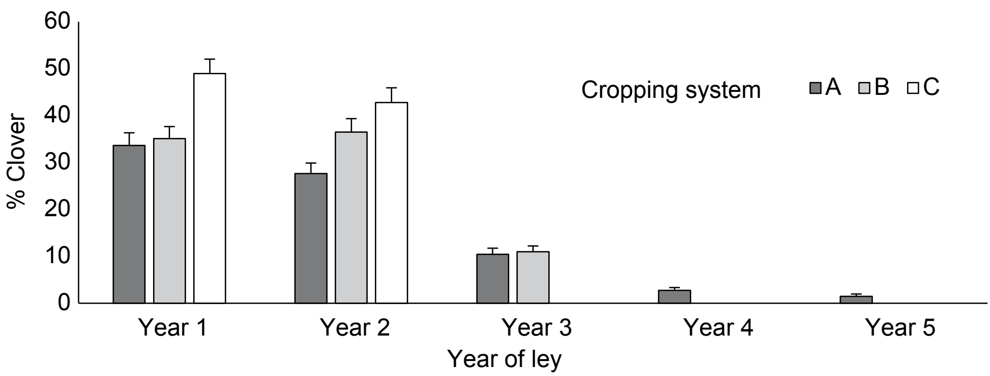

Figure 2. Percentage clover content in each cropping system (A, B and C) in the first harvest of first to fifth year leys. Error bars are one standard error.

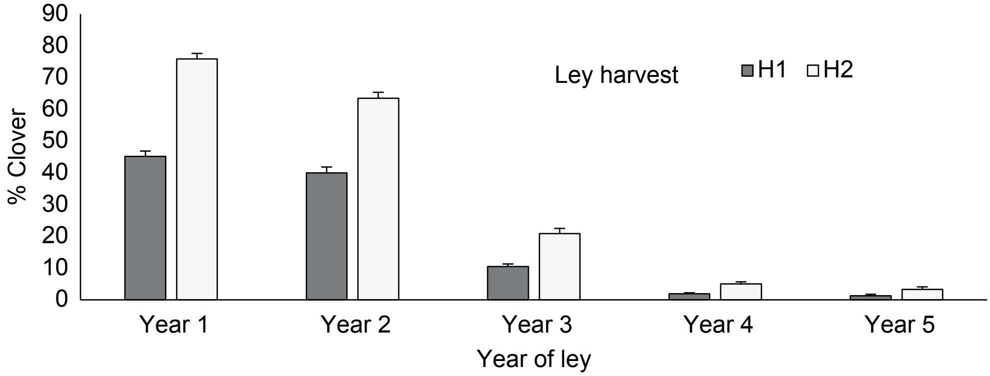

Figure 3. Percentage clover content in the first (H1) and second harvest (H2) of first to fifth year leys. Data for cropping systems A, B and C are combined. Error bars are one standard error.

Conclusions

There were minimal effects of cropping system treatments on ley yields, suggesting that systems with an annual cropping focus can still include a productive ley component. Results also confirm the dynamics of ley clover content within and between years. These results highlight that ley yields are relatively stable regardless of the cropping system but also the challenge of maintaining the legume component in longer term leys.

Acknowledgements

We thank all staff from Ås, Offer and Röbacksdalen since the beginning, for their work on the management and measurement of the experiment. The experiment is financed by the Faculty of Natural Resources and Agricultural Sciences, SLU. The study was conducted using data and material from Röbäcksdalen, SITES (Swedish Infrastructure for Ecosystem Science), a national coordinated infrastructure, supported by the Swedish Research Council.

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The effect of pasture allowance on the performance of growing dairy heifers

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Abstract

Maximising the proportion of grazed grass within the diet of dairy heifers and the achievement of sufficient growth for 24 month calving, will impact on the profitability and sustainability of the dairy enterprise. Grazed grass provides a high protein, low fat diet and remains the cheapest source of high quality feed in ruminant livestock systems. Limited research has looked at the grazing management factors that influence heifer performance. Industry guidelines for pasture allowance (PA) vary from 2.0 to 3.0% for growing cattle. The objective of this study was to investigate the PA for replacement dairy heifers, to achieve optimal animal and pasture performance. Holstein heifers (n = 72) were assigned to three PA treatments at 1.8, 2.4 and 3.0% live weight (LW) allowance of grazed grass d^{-1}. Heifer LW and body condition score were recorded. Compressed sward heights were measured on animal entry and exit to each paddock. Pasture allowance of 3.0% LW kg^{-1} DM of grazed grass allocated $animal^{-1}$ d^{-1}, had a significant improvement in the growth of Holstein heifers compared to lower PA's. A decrease in pasture utilisation was observed whilst grazing area was increased as a result of higher PA and pasture quality was not significantly affected.

Keywords: heifers, grass, pasture allowance, pasture utilisation

Introduction

Heifer rearing contributes a significant cost to dairying systems, yet can be the most commonly overlooked component (Boulton *et al.*, 2015). The dairy industry has experienced significant change over recent decades, however, heifer rearing practices post-weaning remain relatively unchanged. Heifers achieving target weight is key, as failure adversely affects milk production and can result in reduced fertility (McNaughton and Lopdell, 2013). Grazed grass provides a high protein, low fat diet and remains the cheapest source of high quality feed (Shalloo *et al.,* 2004). Pasture allocation is recognised as a key factor in animal production due to its effect on herbage intake (Mayne, 1996). Pasture allowance (PA) will also affect pasture utilisation (PU) and the nutritional value of the sward in subsequent rotations (Combellas and Hodgson, 1979). The objective of the study was to investigate the optimum PA for replacement dairy heifers, to achieve optimal animal and pasture performance. The study hypothesis was that with increasing PA, a greater proportion of heifers would achieve or exceed target weight gain, whilst the pasture utilisation and quality would be reduced.

Materials and methods

The study was carried out at AFBI Hillsborough. Holstein heifers (n = 72) were assigned to three PA treatments at 1.8, 2.4 and 3.0% live weight (LW) allowance of grazed grass d^{-1}. Paddock area was flexible and calculated based on the kg DM demand for the heifers. Treatment groups were set up in triplicate, with groups comprising eight heifers, average five months old with an average weight of 155 kg. The study commenced on 6 April 2017 with a 14 day rotation length (two day paddock residency) in place up to 1 June 2017. Thereafter, a rotation length of 25 days was practiced (three and a half day paddock residency). Each replicate was split into seven blocks (A to G) and further subdivided into paddocks specific to treatment with 1,215, 1,742 and 2,310 m^2 total area available for 1.8, 2.4 and 3.0% PA, respectively. To manage surplus grass production, 46% of the total paddock areas were used for silage production until mid-July and extra grazers were incorporated. They remained separate from the treatment groups and were managed daily, to achieve similar post-grazing heights as the treatment groups in the paddock. Heifer LW and body condition score (BCS) were recorded fortnightly using a manually operated and calibrated weighbridge (Tru Test Ltd, UK). Compressed sward heights were measured with a rising plate meter (Jenquip, New Zealand) and recorded on animal entry and exit to each paddock. Herbage mass was calculated using a predetermined equation calibrated at AFBI Hillsborough (Dale, 2010) and validated weekly by taking grass clippings (Bosch, UK) of 0.2 × 1 m across five random plots within each paddock (total 1.0 m^2) cut above 4 cm. Samples collected were weighed fresh and submitted for laboratory analysis to determine the oven DM (dried at 60 °C for 72 h). Water soluble carbohydrate (WSC), crude protein (CP), acid detergent fibre (ADF) and metabolisable energy (ME) were determined via near infrared spectrometry (0.2 m^2 above 4 cm). Additional samples were retained frozen for assessment of pasture composition. Daily DM intakes were crudely estimated by subtracting the kg DM left available following grazing, from the kg DM allocated, divided by the duration and number of heifers. Paddock area was measured using a measuring wheel (Forge Steel, UK) to the nearest 0.1 m. The data were analysed using GenStat (VSN International, 2015). Data gathered at multiple time points on individual heifers were analysed using repeated measures analysis with correlation between multiple observations of each heifer modelled using a power model of order 1. The main effects of PA and time and their interaction were assessed, taking account of the random effects of paddock and the time intervals observed.

Results and discussion

The differing PA's in this experiment had a significant ($P < 0.001$) effect on the LW performance of the grazing heifers as shown in Figure 1. Heifers offered 3.0% PA recorded an average daily LW gain of 0.82 kg d^{-1} over 159 days at grass, compared to 0.75 kg d^{-1} and 0.64 kg d^{-1} at 2.4 and 1.8% PA, respectively. This could be attributed to the significant effect ($P < 0.001$) that PA had on estimated daily average intakes. The average consumption by 3.0% PA heifers was 1.2 kg DM more d^{-1} compared with 1.8% PA heifers.

Grazing area (GA) required was significantly affected ($P < 0.001$) by PA (data not shown). The 1.8% PA required an average of 66% of the GA that the 3.0% PA heifers required, whilst 2.4% PA required 84% of the GA of 3.0% PA. The 1.8% PA and 3.0% PA had a difference in stocking rate of 1,077 kg LW ha^{-1} on average across the study.

Pasture utilisation was significantly affected ($P < 0.001$) by PA. The 1.8% PA treatment had the highest average PU of 81.5%, whilst the 2.4 and 3.0% PA exhibited PU's of 72.4 and 67.3% respectively. As shown in Figure 2, there were variations in PU amongst months, however, the effect of PA remained consistent. Pasture allowance has previously been shown (Combellas and Hodgson, 1979) to affect the nutritional value of the sward in subsequent rotations as a result of PU effects. In this study, no significant

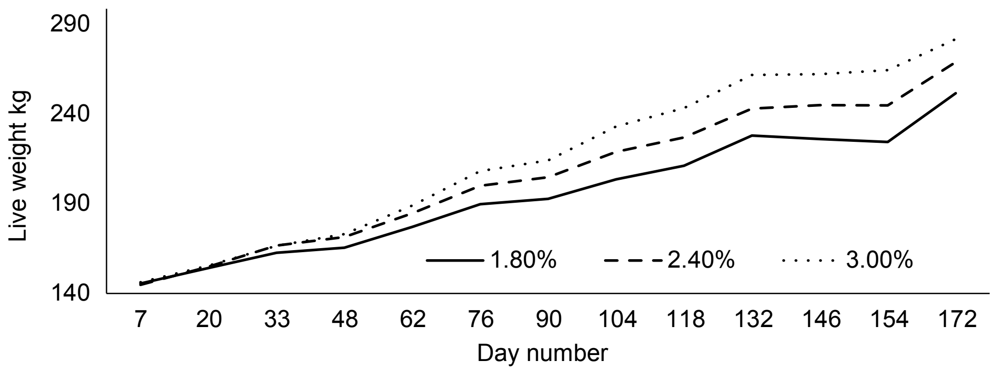

Figure 1. Effect of pasture allowance on heifer live weight.

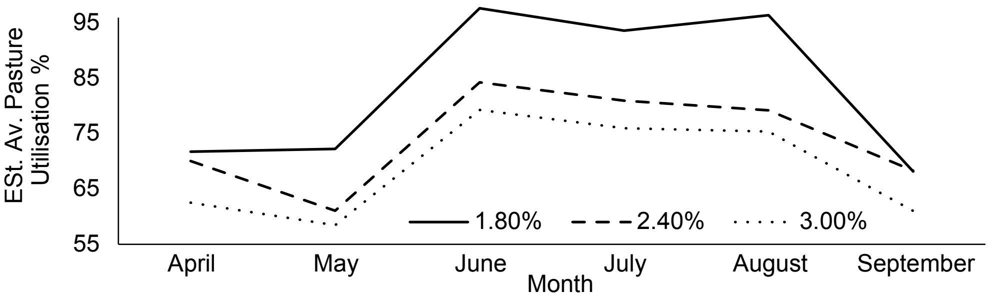

Figure 2. Effect of pasture allowance on pasture utilisation.

effect was found between PA and pasture quality in terms of CP, ME, DM, ADF and WSC. The 3.0% PA showed a greater range and increased fluctuation in ME and ADF over the lower PA throughout the season (data not shown), highlighting the selective grazing behaviour of heifers grazed at higher PA.

Conclusion

Achieving a greater proportion of heifer growth from grazed grass will improve rearing efficiency. Evidence from this study has shown Holstein dairy heifers' can exceed LW gains of 0.80 kg d^{-1} from grazed grass, without concentrates. Pasture allowance of 2.4% gave a LW gain of 0.75 kg day^{-1}, a PU of 72% and required 84% of the GA of the 3.0% balancing animal and pasture performance. Pasture allowance of 3.0% had a reduced increase in LW gain, with an increased LW gain of 0.04 kg d^{-1} between 1.8 and 2.4% PA, over 2.4 and 3.0% PA.

Acknowledgements

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Magnesium and sulfur fertilisation – effects on foliar disease infection in perennial ryegrass

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Abstract

A three-year field experiment demonstrated that magnesium (Mg) and sulphur (S) supplementation in addition to standard nitrogen, phosphorus and potassium fertilisation significantly ($P < 0.001$) reduced the crown rust (*Puccinia coronata*; PC) infection of 33 perennial ryegrass (*Lolium perenne* L.) cultivars cultivated in Mg-deficient soil. The coverage of leaf area by pustules was reduced from 2.6 to 2.4 points on a 1 to 9 scale, with one designating the absence of disease. Leaf spot (*Drechslera siccans*; DS) infection with supplemental Mg-S treatment was increased by 0.1 points ($P < 0.001$) in relation to standard fertilisation. Crown rust resistance of the tetraploid cultivars was significantly ($P < 0.001$) better than diploid cultivars, but tetraploid cultivars were more susceptible to DS ($P < 0.001$). Leaf spot was more injurious to perennial ryegrass than PC as its symptoms developed earlier in summer and occupied a larger leaf area (4.0 and 2.5 points, respectively).

Keywords: diploid, tetraploid, crown rust, leaf spot, resistance

Introduction

In Estonia, fungal diseases annually infect perennial ryegrass (*Lolium perenne* L.; PRG). Crown rust (*Puccinia coronata*; PC) infestation has a negative correlation with herbage DM yield (Dracatos *et al*., 2010). Leaf spot (*Drechslera siccans*; DS) also limits the successful adaptation of PRG varieties (Wiewiora, 2012). Destruction of the leaf tissue following DS infection reduces the photosynthetic surface of the plant (Agrios, 1997). Inherent resistance of the grass cultivars is important to secure high forage production, palatability and quality. Balanced nutrition protects the plants from new infections (Agrios, 1997). We hypothesised that a PRG plants' inherent resistance against fungal pathogens will be enhanced as a consequence of application of a deficient nutrient. We assessed the effect of supplemental magnesium (Mg) and sulphur (S) fertilisation on the two major foliar diseases in PRG.

Materials and methods

A three year field experiment was carried out at the Estonian Crop Research Institute (58°27' N, 26°46' E). There were two treatments, *viz.* with and without Mg-S supplement, imposed on a field fertilised with nitrogen (N), phosphorus (P) and potassium (K). Both treatments comprised 33 (16 diploid and 17 tetraploid) PRG cultivars sown in four replicates to the plots 6.4 m^2 in size. The sowing rates were 30 and 45 kg ha^{-1}, respectively. Before sowing, a compound fertiliser Kemira Power 18-9-9 was applied at a rate of 50 kg N ha^{-1}, 11 kg P ha^{-1} and 21 kg K ha^{-1}. Each of the repeated top-dressings with the same fertiliser was equal to 60 – 13 – 25 kg ha^{-1} of N, P and K. The annual rates of N, P and K totalled 120 – 26 – 50 kg ha^{-1} in 2004, 240 – 52 – 100 kg ha^{-1} in 2005 and 180 – 39 – 75 kg ha^{-1} in 2006. The Mg content in the soil was measured before sowing by the Mehlich III method. As soil Mg was inadequate (105 mg kg^{-1}) for grass cultivation, Mg fertiliser (15% Mg, 3% Calcium and 19% S) was applied to half of the experimental field before sowing. The application of 400 kg ha^{-1} of Kemira Mg fertiliser was calculated to meet the Mg requirements of PRG during the three year experiment. The trial was sown in May 2004 in a randomised complete block design onto *Calcaric Cambisol*, clay loam in texture. The foliar diseases were scored directly before the harvests of PRG. There were nine scorings during three years (Figure 2). Visual estimation, on a scale of 1 - 9, was based on the percentage of foliage area covered by pustules or lesions of the pathogen. The scores between 1 and 9 mean: 1 = no disease, 2 = trace of disease, 3 = 5%, 4 = 10%, 5 = 25%, 6 = 40%, 7 = 60%, 8 = 75% and 9 = > 75% of the foliage covered with symptoms. Data were analysed by single factor ANOVA and Fisher's LSD test using statistical software Agrobase™20. The significance of differences between the means of the ploidy groups of PRG cultivars and the fertiliser treatments were tested with 95% probability.

Results and discussion

Two thousand and four was characterised by abundant precipitation. Monthly mean air temperatures exceeding the long-term averages between August and October favoured the proliferation of both diseases from late August. In 2005, September in particular, air temperatures were warmer than the 90 y average. Although the precipitation remained below optimum for grass growth in June and July, DS started to proliferate. Two thousand and six was extremely hot and dry and was the most stressful to PRG. The monthly mean air temperatures consistently exceeded the long-term averages. Grass growth ceased because the high temperatures were accompanied by severe water deficiency (10 mm in July). However, PRG did not escape from DS. The effect of a rainy second half of August was expressed by a remarkable increase in the infection of both diseases by 28 September (Figures 1 and 2).

Mg-S fertiliser supplement exceptionally favoured the development of PC in October of 2004 by 0.6 points (pts.) relative to NPK fertiliser treatment. As a mean of the year 2004 there was no effect of fertiliser treatment on PC infection rate (Table 1), whereby the tetraploid cultivars were significantly (*P* < 0.001) more resistant (by 0.6 pts.) than diploids. In 2005, the tetraploid cultivars fertilised with Mg-S

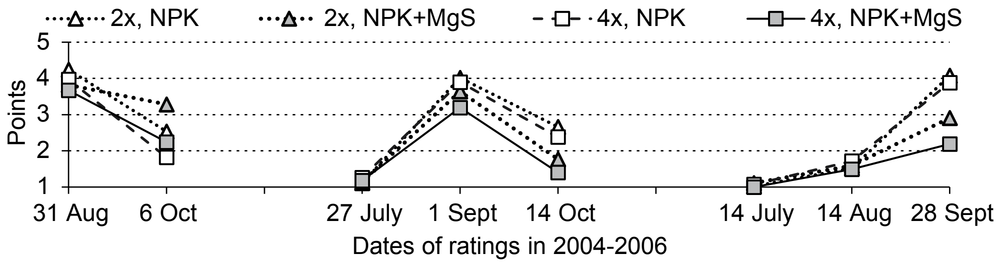

Figure 1. Crown rust infection (scale of 1 - 9, 1 = no infection, 9 = >75% covered with symptoms) of 16 diploid (2 x) and 17 tetraploid (4 x) perennial ryegrass cultivars at two fertilisation treatments: nitrogen (N), phosphorus (P) and potassium (K) or NPK + magnesium (Mg) and sulphur (S) over three years.

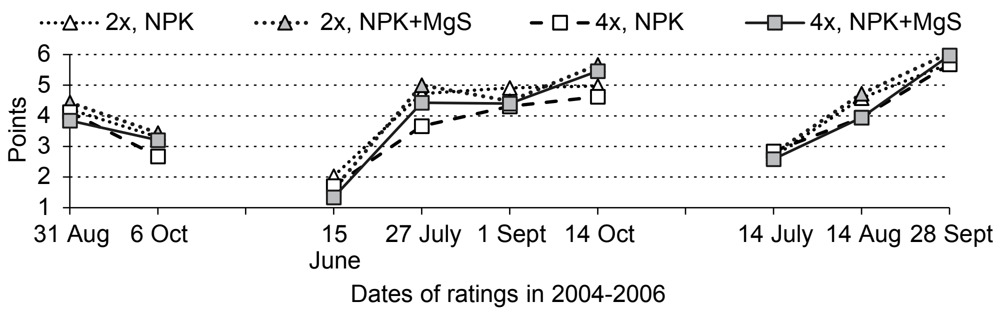

Figure 2. Leaf spot infection (scale of 1 - 9, 1 = no infection, 9 = >75% covered with symptoms) of 16 diploid (2 x) and 17 tetraploid (4 x) perennial ryegrass cultivars at two fertilisation treatments: nitrogen (N), phosphorus (P) and potassium (K) or NPK + magnesium (Mg) and sulphur (S) over three years.

Table 1. ANOVA of the disease scores in 16 diploid and 17 tetraploid perennial ryegrass cultivars at two fertilisation treatments: nitrogen (N), phosphorus (P) and potassium (K) or NPK + magnesium (Mg) and sulphur (S) in 2004 - 2006. 1 = no infection, 9 = >75% covered with symptoms. Significance *** $P < 0.001$; ** $P < 0.01$; ns = $P > 0.05$, not significant.

Year	Crown rust				Leaf spot			
	NPK	NPK+Mg-S	*LSD*	*P*-value	NPK	NPK+Mg-S	*LSD*	*P*-value
2004	3.1	3.3	0.12	ns	3.6	3.7	0.09	**
2005	2.6	2.1	0.11	***	3.9	4.1	0.07	***
2006	2.2	1.7	0.12	***	4.2	4.3	0.09	ns
Mean	2.6	2.4	0.07	***	3.9	4.0	0.05	***

resisted PC the most. However, in 2005 and 2006, at the first observation there was no difference between the two ploidy levels in terms of PC infection. In August 2005 and 2006, the positive effect of MG-S fertiliser supplement on the suppression of PC became evident irrespective of the ploidy of PRG. In these years the MG-S fertiliser supplement significantly ($P < 0.001$) reduced the infection in comparison with the standard NPK treatment. Greater differences were observed between the fertilisation treatments and less between the ploidy groups of PRG.

Variation of scores caused by Mg-S fertilisation or ploidy of PRG was less for DS (Figure 2) than for PC. Although the changes in DS infection in response to fertilisation treatments were vague, the Mg-S supplement tended to favour the pathogen. Supplementary Mg-S fertiliser made both diploid and tetraploid PRG cultivars significantly (by 0.2 and 0.1 pts., respectively) more susceptible to DS. Tetraploid cultivars resisted DS significantly ($P < 0.001$) better (by 0.3 - 0.4 pts.) than diploids in both fertilisation treatments. Braverman (1986) found that tetraploid cultivars were less infected by *Drechslera* spp. than diploids. Leaf spot appeared to be more injurious than PC in our test site. This is evidenced by earlier infection of the swards (15 June 2005), while PC developed its symptoms more than a month later. The maximum coverage of leaves by the symptoms (6.0 pts.) was caused by DS in the NPK+Mg-S treatment.

Conclusions

Supplementary Mg and S in addition to NPK fertilisation exerted a highly significant ($P < 0.001$) effect on PRG cultivars. Crown rust infection was reduced by 0.2 and DS increased by 0.1 pts. The tetraploid cultivars had significantly better resistance against both PC and DS (by 0.2 and 0.3 pts., respectively). Leaf spot appeared to be a more injurious pathogen than PC – mean scores 4.0 and 2.5, respectively. Different dynamics and peaks during the annual infection indicate that DS proliferates at drier weather and cooler temperatures than PC.

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The influence of nitrogen fertiliser and legume content on the quality of multi-species swards

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Abstract

Field trials were carried out to examine the effects of two nitrogen fertilisation application rates, N0 and N120, on the quality of multi-species grass and legume-grass swards for grazing. Twelve mixtures were grouped into four sward types: mixtures composed only of grasses (G); white clover (*Trifolium repens* L.) and grass (Tr + G) mixtures; white clover, red clover (*Trifolium pratense* L.) and grass (Tr + Tp + G) mixtures; bird's-foot trefoil (*Lotus corniculatus* L.) and grass (Lc+G) mixtures. Dry matter (DM) yield was analysed for the following quality indicators and the content of minerals: crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), net energy for lactation (NEL), *in vitro* digestibility, phosphorus (P) and calcium (Ca). Increasing the N fertiliser application rate from 0 to 120 kg ha^{-1} contributed to a significant increase in CP content for all mixtures (on average 21 g kg^{-1}) and phosphorus content increased for legume-grass mixtures (on average 0.4 g kg^{-1}). The ratio of legumes and the legume species used in swards determined the quality and the mineral content of the herbage. Legume-containing mixtures achieved a higher CP and Ca content in comparison with grass-only swards at both fertilisation rates.

Keywords: herbage quality, mineral content, grass-legume mixture, nitrogen fertilisation

Introduction

Legumes are one of the main groups of plants that can improve forage quality. The use of nitrogen (N) fertilisation contributes to increases in DM yield, but, at the same time, has a negative effect on sward legume content (Soegaard and Nielsen, 2012). Crude protein (CP) content is closely related to the proportion of legumes in sward. The type of legumes used in grass-legume mixtures could affect the sward protein content more than the rate of N fertiliser applied (De Vliegher and Carlier, 2008; Meripold *et al.*, 2016). Some researchers have found no significant effect of species or mixtures on the nutritive value of herbage, while increasing the rates of N application can cause a significant increase in CP (Moloney *et al.*, 2016). The objective of this research was to determine the influence of N fertiliser application rate on the herbage quality and botanical composition of multi-species swards in the second production year under the agroclimatic conditions of Latvia.

Materials and methods

Field trials were conducted at three experimental sites in Latvia on soil types: sod- calcareous soil (pH_{KCl} 6.7, the phosphorus (P) and potassium (K) level – 60 mg kg^{-1} and 144 mg kg^{-1}, respectively, and organic matter – 24 - 28 g kg^{-1} of soil), sod-podzolic soils (pH 7.1, the P and K level – 253 and 198 mg kg^{-1} respectively, and organic matter – 31 g kg^{-1}), and sod stagnogley soil (pH 6.33, the P and K level – 93 and 111 mg kg^{-1}, respectively, and organic matter – 23 g kg^{-1}). At each of the three sites, the same 12 mixtures were sown in June 2014 without a cover crop, in 10 m^2 plots with three replications. The multi-component swards were composed of *Phleum pratensis* L., *Dactylis glomerata* L., *Lolium perenne* L., *Lolium boucheanum* L., *Festulolium, Festuca pratensis* L., *Festuca arundinacea* L., *Festuca rubra* L., *Poa pratensis* L., *Trifolium pratense* L., *Trifolium repens* L., and *Lotus corniculatus* L., and grouped in four types: mixtures composed only of grasses (G); white clover (*Trifolium repens*) and grass (Tr + G) mixtures; white clover, red clover (*Trifolium pratense* L.) and grass (Tr + Tp + G) mixtures; bird's-foot trefoil (*Lotus corniculatus* L.) and grass (Lc + G) mixtures. The chemical composition of the plants was determined for the first cut using the following methods: DM – dried; CP – by modified Kjeldahl; nuteral detergent fibre (NDF) and acid detergent fibre (ADF) – by Van Soest. Net energy for lactation (NEL) was calculated on the basis of the chemical composition of DM using digestibility coefficients and full-value coefficients, according to the formula $NEL = (0.0245 \times (88.9 - (ADF\% \times 0.779)) - 0.12) \times 4.184$ (Volden and Nielsen, 2011). The mineral elements P and Ca were analysed by atomic adsorption spectrometry. The average data from the second production year at three experimental sites were statistically analysed using the two-way analysis of variance with mixture type and fertiliser as factors and the difference among means was detected by LSD at the $P < 0.05$ probability level (Excel for Windows, 2003).

Results and discussion

The CP content of the DM yield of multi-species swards in the second production year was essentially influenced by the botanical composition of mixtures and the N rate. Grass-only mixture type (MT) had a significantly lower CP content in comparison with legume-containing MT (Table 1). There were no significant CP differences between different legume-containing MT, either at N0 or N120 treatment. The increase in N fertiliser rate from 0 to 120 kg ha^{-1} contributed to a significant CP content increase in the herbage of all MT.

Legumes accumulated more Ca than grasses and this is a reason for the significantly higher Ca content in all legume-containing MT in comparison with grass-only MT, which is in agreement with Juknevičius and Sabiene (2007). There was no significant effect of N application on Ca content. For all legume-containing MT, N application negatively affected the proportion of legumes in the sward compared to unfertilised plots (Figure 1).

The differences in P content between grass and legume-containing MT were small but statistically significant. The N rate increase contributed to a significant P content increase for legume-containing MT.

Grass-only MT had a significantly higher NDF content in comparison with legume-containing MT at both N rates. There were no significant NDF differences between different legume-containing MT. Nitrogen rates had no significant effect on the NDF content in either grass or legume-containing MT. Significant N application effects on ADF content, NEL and DM digestibility were not found. Mixture type did not significantly affect ADF content, NEL and DM digestibility.

Table 1. Average herbage quality of grass-only and grass-legume swards in the second year of sward use.[1]

Mixture type (MT)	N rate, kg ha^{-1} (N)	Content in DM, g kg^{-1}					NEL, MJ kg^{-1} DM	Digestibility, % of DM
		Crude protein	NDF	ADF	Ca	P		
G	N 0	104.6	568.8	345.2	4.8	3.5	5.9	62.0
	N120	126.5	560.6	326.6	4.8	3.6	6.0	63.4
Tr + G	N 0	164.4	483.1	285.1	9.8	3.8	6.3	66.7
	N120	184.1	447.5	294.5	10.0	4.1	6.3	65.9
Tr + Tp + G	N 0	166.8	481.4	285.0	10.7	3.8	6.3	66.7
	N120	185.9	441.1	289.0	11.0	4.0	6.3	66.4
Lc + G	N 0	166.3	465.4	276.4	9.6	3.6	6.4	67.4
	N120	189.7	451.4	309.5	9.5	4.2	6.1	64.8
Mean		161.0	487.4	301.4	8.8	3.8	6.2	65.4
$LSD_{0.05}$ N		9.59	ns	ns	ns	0.11	ns	
$LSD_{0.05}$ MT		23.50	78.36	ns	4.14	0.27	ns	
$LSD_{0.05}$ N / MT		ns	ns	ns	ns	ns	ns	

[1] ns – not significant; NEL - net energy for lactation.

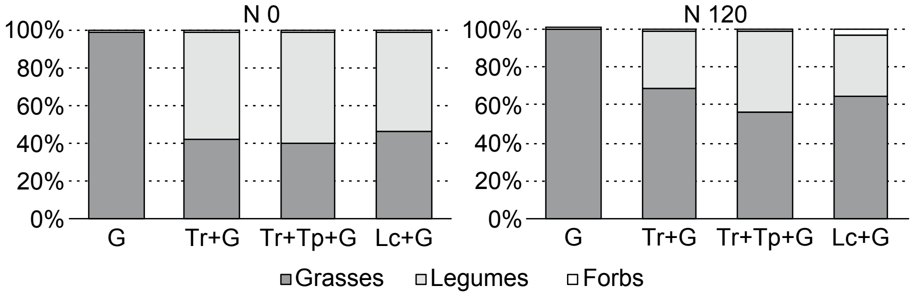

Figure 1. Proportions of the groups of herbage species (%) applying two N fertiliser rates (on average three soil types): G: grasses; Tr + G: white clover, grass; Tr + Tp + G: white clover, red clover, grass; Lc + G: bird's-foot trefoil, grass.

Conclusions

Increasing the N fertiliser rate from 0 to 120 kg ha^{-1} contributed to a significant CP content increase in the DM yield of all mixture types. The use of legume-containing swards can contribute to a better quality of herbage – a higher CP content and a lower NDF content. Legume-containing mixtures for forage may optimise Ca content, thus improving the quality of forages.

Acknowledgements

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The effect of heading date of perennial ryegrass on milk production

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Abstract

Perennial ryegrass is the most common grass species used in the Netherlands. Usually a mixture of different varieties with different heading dates is sown when reseeding. The objective of this research was to examine the effects of mixtures with synchronous heading dates on dairy cow milk production. A mixture with mid heading varieties and a mixture with late heading varieties were sown at the Aeres Innovation Centre Dronten, the Netherlands, in autumn 2015. The first harvest in 2016 was mown beginning of May. As effects of heading dates are mainly expected to occur during the time of flowering in late May/early June, a grazing experiment was carried out during the second harvest of 2016 and 2017. The September 2016 harvest was also grazed and all other harvests were mown. During the three grazing periods, two herds each containing 14 spring-calving dairy cows were allocated to graze the two different mixtures. Results of the first experimental grazing period (26 May to 14 June 2016) showed a higher energy content and digestibility of the mixture with late heading varieties. There was no significant effect of heading date on milk production in the three grazing periods.

Keywords: heading date, milk production, perennial ryegrass

Introduction

Perennial ryegrass (*Lolium perenne* L.) is the most common grass species used in the Netherlands. Usually a mixture of different varieties with different heading dates is sown. Gowen *et al.* (2003) concluded for Ireland that later heading grass varieties have a beneficial effect on the milk production performance of spring calving dairy cows. The objective of this research was to examine the effects of two different mixtures with synchronous heading dates on dairy cow milk production in the Netherlands.

Materials and methods

A perennial ryegrass mixture with an expected mean heading date 23 May (consisting of mid heading varieties) and a perennial ryegrass mixture with an expected mean heading date of 3 June (consisting of late heading varieties) were sown on two parcels with an area of 5 ha each on clay soil at the Aeres Innovation Centre Dronten, the Netherlands, in autumn 2015. Both mixtures contained 40% tetraploid and 60% diploid perennial ryegrass varieties. The varieties were all chosen from the Dutch National recommended list. The first harvest in 2016 and 2017 was mown beginning of May. As effects of differences in heading dates are mainly expected to occur during the time of flowering in late May/early June, a grazing experiment was carried out during the second harvest period of 2016 (26 May to 14 June) and 2017 (27 May to 12 June). All other harvests were mown (July 2016, August 2016) except the September 2016 harvest, which was also grazed (5 September to 18 September). The experiment ended 12 June 2017.

Throughout the experimental period (2015 - 2017), the two parcels were treated identically with respect to grazing dates, mowing dates and fertilisation (dates and application rate). The mean N application rate was 345 kg N ha^{-1} yr^{-1}. During the three grazing periods, two herds each containing 14 spring-calving Holstein-Friesian dairy cows were allocated to graze the two different mixtures. At the beginning of the grazing period, both herds were randomised over the parcels and matched with respect to lactation stage, days in milk and milk production. During the grazing periods, pre and post grazing yields were measured daily either using a Tempex (Eijkelkamp) or a Jenquip rising plate metre, which were both validated for Dutch conditions (Holshof and Stienezen, 2016). VEM (Dutch energy unit), OMD (organic matter digestibility), crude protein content and soluble sugar content of the grass were determined twice per week. Milk production was measured twice per day during milking. Fat and protein content of the milk was measured weekly.

Because of the case-control design of our study, independency cannot be assumed and hence repeated measure ANOVA to test for possible effects of treatment on the daily milk production (kg milk cow^{-1}). Factors included: TimePoint (Null, Start, FirstMiddle, SecondMiddle and End) and Treat (M: mixture with mid heading varieties, L: mixture with late heading varieties). Milk production was measured for three days prior to the experiment (Null). The experimental grazing period was divided into four equal time windows (i.e. Start, FirstMiddle, SecondMiddle and End). Analyses were performed using IBM SPSS version 22. Alpha was set at 0.05. Corrections for assumed sphericity and multiple comparisons were used when applicable by means of the Huyhn-Feldt and Bonferroni corrections, respectively. Post-hoc tests were performed between treatment groups (i.e. M and L) for every level within the TimePoint factor. A t-test was used to test for possible effects of treatment on grass yield and quality.

Results and discussion

The expected effects of differences in heading dates are mainly expected to occur during the flowering period (late May/early June). Results of the first experimental grazing period (26 May to 14 June 2016) showed that, on average, time did influence the obtained milk production as evident from the significant main effect of TimePoint ($F(4,52) = 19.873$; $P < 0.001$; $\eta^2 = 0.605$); Figure 1.

No significant effect of Treat was found ($P > 0.05$). A significant interaction of TimePoint × Treat was obtained ($F(4,52) = 3.720$; $P < 0.05$; $\eta^2 = 0.222$). Differences in milk production between treatments over the different time points gave rise to this interaction. Post-hoc analyses, however, showed no significant differences between treatment for any of the time periods (all $P > 0.05$).

In the first grazing period (26 May to 14 June 2016), DM yield of the mixture with the late heading varieties exceeded the DM yield of the mixture with the mid heading varieties. For both treatments, the daily herbage allowance for the grazing dairy cattle was set *ad libitum*. Mean pre grazing grass height was 21 cm and mean post grazing grass height was 13 cm. There were no significant differences in grass

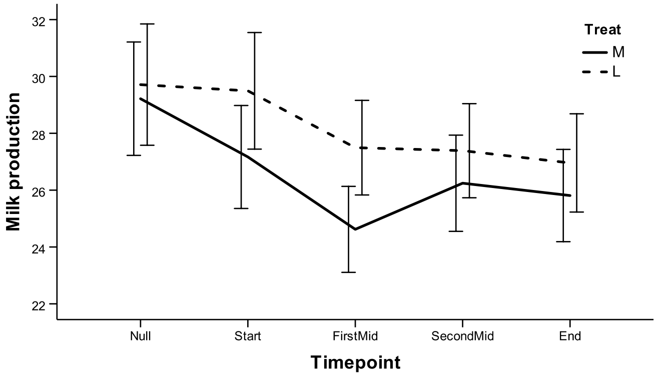

Figure 1. Milk production per time period for the two treatment groups (M = mixture with mid heading varieties, solid line; L = mixture with late heading varieties, dotted line) during the grazing period of May / June 2016. Error bars denote mean ± SEM (standard error of the mean).

intake between the two herds. The mean daily grass intake was 16 kg DM cow^{-1}. The VEM and OMD were higher for the mixture with the late heading varieties than for the mixture with the mid heading varieties (Table 1).

O'Donovan and Delaby (2005) found that the better sward quality of mixtures with late heading dates allowed cows grazing to improve their milk production performance in Ireland. The higher energy content and digestibility of the mixture with the late heading varieties in the flowering period of 2016 did not lead to differences in milk production in the Netherlands. Furthermore, there were no significant differences in milk production and grass quality between treatments in autumn 2016 and in the flowering period of 2017 ($P < 0.05$; results not shown). The weather conditions during the flowering period in 2017 were quite extreme and may have affected the results. High temperatures (25 - 30 °C) and drought prior and during the grazing period induced early flowering, leading to a difference in flowering between mid heading varieties and late heading varieties of only two - three days instead of the expected 11 days.

Table 1. Grass quality parameters for the two treatments (mixture with mid heading varieties and mixture with late heading varieties) during the first grazing period of 2016 (mean ± SEM; SEM=standard error of the mean, n.s. = not significant at 0.05 level.

	Mid	Late	*P* value
VEM[1], kg^{-1} DM	891 ± 36	940 ± 17	0.005
OMD[1], % DM	76.88 ± 0.58	80.16 ± 0.62	0.027
Crude Protein, g kg^{-1} DM	133 ± 7	134 ± 6	n.s.
Soluble Sugar, g kg^{-1} DM	194 ± 20	232 ± 11	n.s.

[1] VEM = Dutch energy unit; 1 VEM = 6,9 kJ net energy for lactation; OMD = organic matter digestibility.

Conclusions

Two perennial ryegrass mixtures with synchronous heading dates (a mixture of mid heading varieties and a mixture of late heading varieties) were tested during three grazing periods in 2016 and 2017. Results of the first grazing period (26 May to 14 June 2016) showed a higher energy content and digestibility of the mixture with late heading varieties. There was no significant effect of heading date on milk production in the three grazing periods.

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Persistence of modern varieties of *Festuca arundinacea* L. and *Phleum pratense* L. as an alternative to *Lolium perenne* L. in intensively managed sown grasslands

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Abstract

Demands on grass swards are changing. Adaptation to climate change and interactions with management and site are becoming more important. In order to investigate the potential of two alternative grass species to *Lolium perenne* L. (*Lolium pr.*), we set up a field experiment with modern varieties of *Festuca arundinacea* Schreb. (*Festuca ar.*) and *Phleum pratense* L. (*Phleum pr.*) with *Lolium pr.* as a reference on three sites – a clay, a peat and a sandy soil. Each of these grasses were sown as the main species in mixtures with *Poa pratensis* L. and *Trifolium repens* L. and subjected to different management schemes as distinguished by frequency of defoliation. We tested how yields and sward composition changed over time. Differences in yield proportions in the third year were significantly influenced by main species, site and their interaction. Remaining yield proportions of main species were smallest on peat on all sites. *Festuca ar.* showed the highest persistence, followed by *Lolium pr*. Yield proportions of *Phleum pr.* were especially small on peat where it had been replaced by *Holcus lanatus* L. We conclude that when yield stability is of concern, new varieties of *Festuca ar.* are an interesting alternative, especially on peat land.

Keywords: persistence, variety, *Festuca arundinacea*, *Phleum pratense*, *Lolium perenne*

Introduction

The introduction of valuable forage species is a proven measure to make grasslands more productive (Frame, 1992). After renovation, the composition of the new sward will undergo changes and the success of the renovation will depend greatly on site conditions and management. It is often the case that after some time sown mixtures are replaced by species and varieties that had not been sown. The vegetation development is influenced by use as grazing or cutting. *Lolium perenne* L. (*Lolium pr.*) survives longer in the sward under grazing and is well adapted to clay soils and a more maritime climate (Frame, 1992). Water supply, drainage and the amount of organic matter influence the development of swards as well – peat lands are particularly difficult to manage. Climate change is expected to lead to a higher probability of drought periods in summer and this will especially affect grass growth on sandy and peat soils. With this background we aimed at testing alternative grass species to *Lolium pr*. *Festuca arundinacea* Schreb. (*Festuca ar.*) is highly competitive and shows a good persistence under cutting and drought but also a good tolerance to water logging (Suter *et al.*, 2009; Cougnon *et al.*, 2013). Unlike before, new varieties have softer leaf tissue, less silicate and are much better accepted by livestock (Suter *et al.*, 2009). *Phleum pratense* L. (*Phleum pr.*) is sensitive to a high frequency of defoliation, but provides a good feed value and a tolerance to cold periods (Höglind *et al.*, 2010; Suter *et al.*, 2009). We set up a three-year experiment with different mixtures and management on sites with differing soils (Table 1).

Materials and methods

The experiment was established in autumn 2013 on three sites (sandy soil, peat soil, clay-marsh soil) in north-west Germany. The main species *Lolium pr.*, *Festuca ar.,* and *Phleum pr.* were accompanied by *Trifolium repens* L. and *Poa pratensis* L. and subjected to a simulated grazing regime, a mixed regime with a first cut followed by simulated grazing and a cutting-only regime (Table 1). The experimental layout

Table 1. Set up and management of the experiment.

Factor	Steps	Notes
Mixture (main species)	*Lolium perenne* cv.Sponsor *Festuca arundinacea* cv. Elodie *Phleum pratense* cv. Barpenta	Sown mixture = 25 kg ha^{-1} main species + 3 kg *Poa pratensis* (cv. Lato) + 3 kg *Trifolium repens* (cv. Rivendel)
Management	Grazing (sim.) Mixed Cutting-only	Simulated grazing with 7 cuts; mixed with 6 cuts, and cutting-only with 4 cuts per year
Site	Sand / Geest landscape Clay / Marsh land Peat / Moor land	Experiment repeated on three different sites; 3 years; 3 blocks; split-plot design

at each site followed a split-plot design with the treatment management forming sub-blocks within three main blocks (replications) and mixtures (plots) randomly allocated to the sub-blocks. Cutting for the simulated grazing started between 05 and 15 April, the mixed plots and the cutting system were harvested between 15 and 25 May for the first time. The cutting-only plots were harvested every six weeks after the first cut. Plot size was 1.5 × 7.0 m and harvested in total with a remaining stubble height of 4 cm. Grab samples of 500 g were used to determine DM content and for further analyses. All plots received 320 kg nitrogen (N) ha^{-1}, 75 kg phosphorous (P) ha^{-1}, and 150 kg potassium (K) ha^{-1} per year; after an initial supply of N (60 kg N ha^{-1}) in March together with P and K, the remaining N was applied after each cut. Mass proportions of each species were determined by separation of grab samples from every plot in July of the third year. For statistical analysis we used the lme function from the nlme package (Pinheiro *et al*., 2017) in R Studio (RStudio Team, 2016). Site, mixture/sward composition and management were considered as fixed factors in a mixed model approach; replications in blocks and sub-blocks were taken as random factors.

Results and discussion

The sward composition at the end of the third year was, depending on site and mixture, distinctly different from the sown mixtures (Figure 1). The remaining proportions of the main species did not differ greatly between simulated grazing, mixed and cutting. Management had no significant effect on persistence, but persistence differed among sites ($P < 0.003$) and mixtures ($P < 0.001$) and mixtures responded differently in their development to site conditions ($P = 0.0043$). Comparing the main species as an average of the three management regimes and sites (Figure 1), remaining proportions of *Phleum pr.* were lowest (48%) and those of *Festuca ar.* the highest (89%) with proportions for *Lolium pr.* being only slightly less (76%) than *Festuca ar.* All proportions of the main species were most reduced on the peat soil ($P < 0.05$) and particularly for *Phleum pr.* with values as low as 20% compared to 75% for *Festuca ar.* and 59% for *Lolium pr.* Generally, the persistence of the main species correlated with the annual yield in the third year ($r = 0.56$; $P < 0.001$) and even more so with yield at the sampling date ($r = 0.60$; $P < 0.001$). *Phleum pratense* L. showed the greatest reductions and was displaced by *Holcus lanatus* L. on the peat soil and by the accompanying grass *Poa pratensis* L. on the sandy and clay soil. On the peat soil the reduction of *Phleum pr.* was already evident in the first year. Despite these changes in sward, composition yields were much less affected. In the third year, *Phleum pr.* and *Holcus lanatus* L. did produce good yields on the peat soil (8.8 t DM ha^{-1}), but the combination of increased proportions of *Poa pratensis* L. with less *Phleum pr.* on the sandy and clay soil in particular, produced yields (12.1 t ha^{-1}) that were similar to *Lolium pr*. (11.6 t ha^{-1} on sand; 13.7 t ha^{-1} on clay). *Festuca arundinacea* Schreb. based mixtures proved to be most competitive and even managed to persist on the peat soil (11.5 t ha^{-1} on peat; 16.6 t ha^{-1} on sand; 18.1 t ha^{-1} on clay). Other studies also observed a good persistence and yield stability of *Festuca ar.* on peat soils (Kalzendorf and Hinrichsen, 2017).

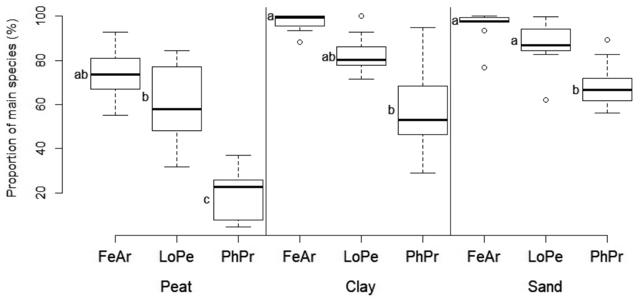

Figure 1. Persistence of the sown grass species: proportion of the main species of the total sward composition after three years as averaged over the three types of managements (sim. grazing, mixed, and cutting-only), median, box and whiskers. FeAr: *Festuca arundinacea*, LoPe: *Lolium perenne*, PhPr: *Phleum pratense*. Different letters indicate significant differences among means.

Conclusions

The use of *Festuca ar.* might help to reduce the frequency of sward renovations on peat soils and thus reduce the mineralisation of organic carbon in the soil. Combining *Lolium pr.* and *Festuca ar.* is also an interesting option and could result in stable forage production during dry periods, especially on lighter soils, and a good forage quality. However, caution needs to be used when generalising the results as variety choice may impact persistency.

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Variations of the herbage energy to protein ratio in lucerne-based mixtures as influenced by cutting management

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Abstract

The herbage energy to protein ratio affects ruminant N use efficiency but little is known about its variation in lucerne (*Medicago sativa* L.)-based mixtures. We determined the effects of four cutting management strategies (cuts at early bud with an autumn cut; early bud with no autumn cut; early bloom with an autumn cut; early bloom with no autumn cut) and four lucerne-based mixtures (Lucerne; Lucerne + Timothy (*Phleum pratense* L.); Lucerne + Tall fescue (*Schedonorus phoenix* (Scop.) Holub); Lucerne + Timothy + Meadow fescue (*Festuca elatior* L.)) at three successive harvests on the herbage ratio of water soluble carbohydrates (WSC) to crude proteins (CP) over three post-seeding years at three climatically-contrasted sites in eastern Canada. The herbage WSC:CP ratio was greater at the first harvest than at the second and third harvests for all lucerne-based mixtures and cutting management strategies. The herbage WSC:CP ratio at the first harvest was greater for cutting strategies with an autumn cut than without an autumn cut. Pure lucerne had the lowest herbage WSC:CP ratio at the three harvests. The greater herbage WSC:CP ratio at the first harvest, for cutting strategies with an autumn cut, and in mixtures that included grasses is explained by a lower proportion of lucerne in the harvested herbage.

Keywords: herbage species, carbohydrates, proteins, energy, cutting

Introduction

Enhanced efficiency of nitrogen (N) utilisation and enhanced milk yield were reported for cows fed grasses or lucerne with a high non-structural carbohydrate concentration (Miller *et al.*, 2001; Brito *et al.*, 2009). For improved N utilisation by dairy cows, a dietary combination of high energy availability and reduced total N concentration has been suggested for better microbial protein synthesis in the rumen (Bryant *et al.*, 2012). Parsons *et al.* (2011) concluded that the herbage water soluble carbohydrates (WSC):crude protein (CP) ratio, ranging from 0.5 to 2.4, was negatively correlated with N excreted in the urine. In studies conducted in eastern Canada, the herbage WSC:CP ratio varied from 0.39 to 0.70 among 18 legume-grass binary mixtures (Simili da Silva *et al.*, 2013) and from 0.64 to 1.04 among eight legume-grass complex mixtures (Simili da Silva *et al.*, 2014). These results obtained from the first two harvests of the first post-seeding year provided useful and novel information on the possibility to improve the balance between herbage readily-available energy and proteins. However, no study has ever been conducted in Canada on the effects of the stage of development at harvest, the herbage mixtures harvested for silage or hay and time of year on the herbage WSC:CP ratio. Our objective was to determine the effects of cutting management strategies based on the stage of development at cutting combined or not with an autumn cut, lucerne-based mixtures with different grass species and harvests from different periods during the growing season on the herbage WSC:CP ratio.

Materials and methods

An experiment was established in 2013 at three sites in eastern Canada with a climate gradient: Normandin, 1359 growing degree-days (GDD, 5 °C basis); Saint-Augustin-de-Desmaures, 1712 GDD; and Sainte-Anne-de-Bellevue, 2098 GDD. The experiment was conducted over three post-seeding years

(2014 to 2016). Four cutting management strategies (cuts at the early bud stage with an autumn cut; cuts at the early bud stage with no autumn cut; cuts at the early bloom stage with an autumn cut; cuts at the early bloom stage with no autumn cut) and four lucerne-based mixtures (Lucerne; Lucerne + Timothy; Lucerne + Tall fescue; Lucerne + Timothy + Meadow fescue) were arranged with four replications in a randomised complete block design with split-plot restriction with cutting management strategies as main plots and lucerne-based mixtures as sub-plots. The herbage was cut in each plot with a self-propelled flail harvester to a 7 cm height at least three times per year. At each harvest a herbage sample of around 500 g was dried at 55 °C for three days and analysed for WSC and CP concentrations (Simili da Silva *et al.*, 2013). The proportion of lucerne was assessed at each cut by hand separation of a sample from a 50 × 50 cm area in each plot. Data were assessed across treatments by analyses of variance with years and sites as random effects and cutting management strategies, lucerne-based mixtures and the first three harvests during the growing season as fixed effects.

Results and discussion

Cutting management strategies, lucerne-based mixtures and harvests significantly affected the herbage WSC:CP ratio. The effect of the cutting management strategies and lucerne-based mixtures, however, varied with the harvests as indicated by their significant interaction with harvests. Averaged across the three post-seeding years and the three sites, the herbage WSC:CP ratio was significantly greater at the first harvest than at the second and third harvests for all cutting management strategies (Figure 1A) and lucerne-based mixtures (Figure 1B). The herbage WSC:CP ratio at the first harvest was greater for cutting strategies with an autumn cut than without an autumn cut and the lowest at the second and third harvests with cutting at the early bloom stage of development with no autumn cut (Figure 1A). Pure lucerne had the lowest herbage WSC:CP ratio at the three harvests and the ratio tended to be greatest in Lucerne + Timothy + Meadow fescue at the first harvest and in Lucerne + Tall fescue at the second and third harvests (Figure 1B).

The generally greater WSC:CP ratio for cutting strategies with an autumn cut, mixtures of lucerne with grasses and the first harvest can be in part related to a lower proportion of lucerne in the mixture. Averaged across years and sites, the proportion of lucerne was the lowest with cuts taken at early bud and an autumn cut (54%) and the greatest with cuts taken at early bloom and no autumn cut (75%).

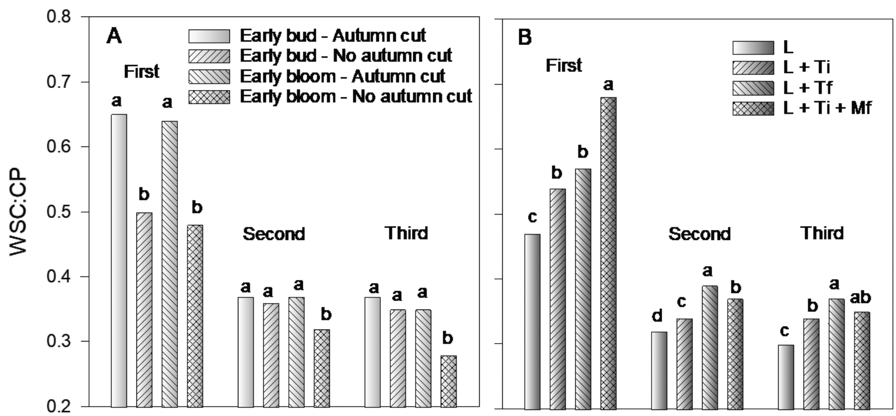

Figure 1. Herbage water soluble carbohydrate (WSC) to crude protein (CP) ratio for the main effects of four cutting management strategies (A) and four lucerne-based mixtures (B) at the first, second and third harvests during the growing season. Data are averages of three post-seeding years over three sites, L: Lucerne, Ti: Timothy, Tf: Tall fescue, Mf: Meadow fescue. Within a harvest, different letters indicate a significant difference at $P < 0.05$.

The proportion of lucerne was also lower with Lucerne + Timothy (68%), Lucerne + Tall fescue (56%), and Lucerne + Timothy + Meadow fescue (51%) than with pure lucerne (82%), and lower at the first harvest (55%) than at the second (71%) and third harvests (68%). Overall, the herbage WSC:CP ratio was negatively correlated to the proportion of lucerne in the mixture (r = -0.57, P < 0.001, n = 560). Herbage grasses are known to have greater WSC and lower CP concentrations than herbage legumes.

Conclusions

Our results confirm that cutting management strategies, companion grass species and harvests corresponding to different periods during the growing season affect the herbage energy to protein ratio in lucerne-based mixtures. The herbage WSC:CP ratio was greatest at the first harvest, for cutting strategies with an autumn cut, and in mixtures that included grasses due a lower proportion of lucerne in the harvested herbage. Research is ongoing to provide on overall perspective of the effect of those three factors on herbage yield and all attributes of nutritive value.

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Performance of *Lolium* spp., *Festuca* spp. and their mutual hybrids in Latvian conditions

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Abstract

Interspecific hybridisation is carried out with the aim of combining the best properties of each species in one cultivar: quality and yield potential of *Lolium* spp., winter-hardiness of *Festuca pratensis* L. (*Fp*) and persistence of *Festuca arundinacea* L. (*Fa*). Depending on the parent and their genome proportion, the hybrids of ×*Festulolium* (*FL*) tend to vary greatly, providing different productivity, forage quality, persistence, etc. The aim of our studies was to evaluate and compare the commercial cultivars of *Lolium perenne* L. (*Lp*), *Fp, Fa, FL* and *FL* hybrids differing in parental origin over four consecutive climatically different years (2013 - 2016). The data shows that the DM yield (DMY) depending on the ley year and wintering conditions varied between 4.71 and 6.17 t ha^{-1} for *Lp*; 5.94 and 8.13 t ha^{-1} for *Fp*; 8.46 and 10.95 t ha^{-1} for *Fa*. Very different DMY (3.88 - 12.81 t ha^{-1}), often greater than that of the parent species, were measured for *FL* hybrids, depending on their parental origin and species on which cytoplasmic base they were developed. Significant fluctuations in terms of DMY of *Lp* and some *FL* hybrids were observed in the 2nd season after a very cold winter, however, individual hybrids showed an outstanding ability to rejuvenate the sward during vegetation.

Keywords: *Festulolium*, breeding, species, DMY, persistency

Introduction

In the Latvian climate, *Lolium perenne* L. (*Lp*) is often not sufficiently winter-hardy and persistent (Berzins *et al*., 2017), therefore, interspecific hybridisation is performed by mutual pollination of *Lp*, *Festuca pratensis* L. (*Fp*) and *Festuca arundinacea* L. (*Fa*). *Festuca* spp. and *Lolium* spp. are closely related in evolutionary terms, therefore they can be hybridised successfully (Ostrem *et al*., 2013). Important requirements for ×*Festulolium* (*FL*) hybrids are combining productivity, growth potential and forage quality of *Lolium* spp. with a stress tolerance, including cold resistance and winter-hardiness of *Festuca* spp. (Thomas *et al*., 2003). Both, *Lp* and *FL* usually survive well in the 1st winter after sowing. In the following years, depending on winter conditions and cultivar, survival can be sufficiently high (70% - 90%) or it can decrease dramatically (Berzins *et al.*, 2017). However, *FL* has the ability to rejuvenate reasonably well after adverse winter conditions. These abilities depend greatly on the characteristics of each cultivar. The most interesting for Nordic and Baltic conditions are festucoid type *FL* cultivars (crosses between *Lolium multiflorum* L. and *Fa*) due to their high yield ability and persistency (Østrem and Larsen, 2008; Halling, 2012). In Latvia, the main focus is directed towards developing hybrids with *Fa* (*Lp* × *Fa*; *Fp* × *Fa*) and the main challenge is to improve palatability and forage quality of these hybrids.

Materials and methods

The potential of *FL* for forage production in Latvian conditions was investigated by comparing three promising Latvian *FL* hybrids differing in parental origin with commercial cultivars of *FL* (Vizule, Perun, Felina) and parental species: *Lp* Spidola (4n), *Fp* Silva, and *Fa* Swai. Seeding rate of 25 kg ha^{-1} was used for all cultivars. The field experiment was established in a randomised complete block in four replicates on 20 August 2012 and conducted from 2012 to 2016 in the central part of Latvia (56°37' N, 25°07' E) in sod-podzolic sandy loam soil (Eutric Retisol – WRB 2015) with 5.3 pH KCl, 27.0 g kg^{-1}organic matter content, 167.1 mg kg^{-1} plant available phosphorus (P_2O_5) and 88.0 mg kg^{-1} potassium (K_2O). The DM yield (DMY) was recorded from an accounting area of 10 m^2 using three cuts per season (1st cut at the beginning of heading; 2nd and 3rd cut (aftergrass) 30 - 40 days after previous mowing). Visual scoring of culm formation (1 - 9 scale), species cover in the sward (%) and leaf softness (1 - 9 scale) by touch at different stages of development were performed. Relative fodder value (RFV), what is relative number for comparison of fodder quality (for high-quality fodder it should exceed 100) was calculated from acid detergent fibre (ADF) and neutral detergent fibre (NDF) content of the forages at 1st and 2nd harvesting. The field was not fertilised before sowing; in the production years, ammonium nitrate was used three times per year (in total 180 kg nitrogen (N)): in early spring just after the beginning of vegetation and after the 1st and 2nd cut (60 kg N per application). In addition, in autumn after harvesting, complex fertiliser, providing 15:30:75 kg ha^{-1} N, P_2O_5 and K_2O respectively, was used. In all experimental years, meteorological conditions at the test site were within the normal range, except for unfavorable wintering conditions during 2013/2014, when for about three weeks black frost (-20 to -25 °C) with cold winds were present. The experimental data were processed by the analysis of variance (ANOVA); differences between means were detected by least significant difference (LSD) at the 0.05 probability.

Results and discussion

Due to unfavorable conditions at the test site during 2013/2014, many swards of *Lp* and *FL* were severely damaged. The majority of swards partly renewed themselves over the following season and provided a satisfactory DMY in the following years. The *FL* hybrid PSP (*Fp* × *Lp*), originated from *Fp* cytoplasm, was least affected by black frost (Table 1).

No winter damage was observed for *Fp*, *Fa* and *FL* hybrids that originated from *Fa* as species within the genus *Festuca* have a higher level of general stress tolerance than *Lp* (Ostrem *et al*., 2013). The DMY of these species and hybrids after the severe winter conditions in the 2nd ley year were higher than in the 1st ley year: DMY ranged from 8.13 t ha^{-1} for *Fp* to 12.81 t ha^{-1} for the *FL* hybrid GNK (*Lp* × *Fa*), which overall proved to be the most productive over four ley years. Despite good winter-hardiness, *Fp* does not survive much longer than *Lp* and *FL* (Table 2). That is why it is necessary to develop hybrids with *Fa*, which are persistent and highly productive species. During four ley years *Fa* and its hybrids with *Lolium spp.* and *Fp* were distinguished by their high productivity and persistency, which, however, produced fodder of lower quality. The main problem was the harsh-leaved sward of *Fa* that significantly reduced the palatability of the grass. The hybrids with *Fa* showed slightly improved leaf softness; on a 9 point scale they scored 4 and 5 points, whereas *Fa* scored 3 points (Table 2).

Table 1. The DM yield (DMY) and proportion of aftergrass (2nd and 3rd cut) of different grass species swards in four ley years (2013-2016).[1]

Origin**	Cultivar /	DMY, t ha^{-1}					DMY % to *Lp*	DMY of aftergrass	
	FL hybrid*	1st ley year	2nd ley year	3rd ley year	4th ley year	Average of 4 years		% of total yield	% relative to *Lp*
Lp	Spidola	6.17^{c}	4.71^{e}	5.77^{e}	5.56^{bc}	5.55^{e}	100.00	43.70	100.00
Lp × *Fp*	Vizule	7.64^{ab}	5.63^{d}	7.98^{cd}	6.00^{b}	6.81^{d}	122.64	45.13	103.28
Lm × *Fp*	Perun	7.42^{b}	3.88^{f}	6.72^{de}	5.11^{c}	5.78^{e}	104.09	48.14	110.16
Fp × *Lp*	PSP*	7.62^{ab}	6.56^{d}	7.25^{d}	5.46^{bc}	6.72^{d}	121.02	38.00	86.96
Fp	Silva	6.46^{c}	8.13^{c}	7.25^{d}	5.94^{b}	6.94^{d}	125.04	43.36	99.23
Lm × *Fa*	Felina	8.08^{ab}	10.16^{b}	10.99^{ab}	7.14^{a}	9.09^{b}	163.76	52.31	119.71
Lp × *Fa*	GNK*	7.89^{ab}	12.81^{a}	11.61^{ab}	7.15^{a}	9.87^{a}	177.67	58.51	133.88
Fp × *Fa*	PatNa*	6.42^{c}	9.63^{bc}	8.60^{c}	5.57^{bc}	7.56^{c}	136.07	58.42	133.69
Fa	Swai	8.46^{a}	10.95^{b}	10.34^{b}	5.54^{bc}	8.82^{b}	158.90	56.02	128.19
$LSD_{0.05}$		0.88	0.91	0.85	0.53	0.46			

[1] ***Lp - Lolium perenne; Fp - Festuca pratensis; Lm - Lolium multiflorum; Fa - Festuca arundinacea*; means with different superscript letters differ significantly within columns ($P < 0.05$).

Table 2. Assessment of *FL* hybrids in field conditions and their relative fodder value (RFV).

Origin**	Culti-var / *FL* hybrid*	Culm forma-tion in after-math, 1 - 9	Soft-ness of leaves, 1 - 9	Species cover in the sward in 4th ley year		Relative fodder value (RFV)		Average RFV in proportion of DMY	RFV relative to *Lp* %
				%	% to *Lp*	1st cut	2nd cut		
Lp	Spidola	4.0	9.0	58.0^{c}	100.0	123.91^{ab}	108.05^{b}	116.98	100.0
Lp × *Fp*	Vizule	6.0	9.0	52.0^{cd}	89.7	124.15^{ab}	100.54^{c}	113.49	97.0
Lm × *Fp*	Perun	8.0	9.0	43.0^{d}	74.1	112.28^{b}	128.94^{a}	120.30	102.5
Fp × *Lp*	PSP*	4.0	9.0	60.0^{c}	103.5	126.05^{a}	106.78^{b}	118.73	101.5
Fp	Silva	1.0	9.0	53.0^{cd}	91.4	97.87^{c}	116.38^{ab}	105.90	90.5
Lm × *Fa*	Felina	2.0	4.0	78.0^{ab}	134.5	103.76^{bc}	110.54^{ab}	107.30	91.7
Lp × *Fa*	GNK*	2.0	3.0	80.0^{a}	137.9	102.24^{bc}	105.43^{bc}	104.10	89.0
Fp × *Fa*	PatNa*	2.0	5.0	80.0^{a}	137.9	100.66^{bc}	119.38^{ab}	111.60	95.4
Fa	Swai	2.0	3.0	71.0^{b}	122.4				
$LSD_{0.05}$				8.40		22.41	19.11		

[1] ***Lp - Lolium perenne; Fp - Festuca pratensis; Lm - Lolium multiflorum; Fa - Festuca arundinacea*; means with different superscript letters differ significantly within columns ($P < 0.05$).

Hybrids of *FL,* originating from *Fa* (PatNa and GNK), are highly productive but the relative fodder value (RFV) showed that their nutritional value is lower than that of *Lp* and *FL* hybrids originating from *Fp*.

Conclusions

We have succeeded in developing several perspective *FL* hybrids that show greater productiveness and persistence, but the activities should be continued to further improve the palatability and forage quality of *Lp* and *Fp* hybrids with *Fa*.

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Understanding factors associated with the grazing efficiency of perennial ryegrass varieties

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Abstract

Herbage utilisation is of primary importance to grassland farmers due to its strong association with farm profit. On commercial grassland farms, grazing efficiency of grass varieties can influence herbage utilisation. To understand grazing efficiency, the interaction between plant and animal is critical; mechanically simulated grazing protocols are limited in the information they provide. The objective of this paper was to understand the grazing efficiency of perennial ryegrass (*Lolium perenne* L.) varieties by identifying grazing traits for use as selection criteria by breeders to develop varieties with improved grass utilisation. Fifty five perennial ryegrass varieties, both diploid and tetraploid with intermediate and late heading dates, were sown in plots. Swards were rotationally grazed by lactating dairy cows in 2015 and 2016. Sward structural, morphological and chemical characteristics were measured and related to grazing efficiency, as measured by post-grazing sward height. Varieties were shown to differ in their level of grazing efficiency ($P < 0.001$). Tetraploid varieties had significantly ($P < 0.001$) greater grazing efficiency than diploids with post-grazing sward heights of 3.8 and 4.1 cm, respectively. Increased free leaf lamina ($P < 0.001$), tiller mass ($P < 0.05$) and dry matter digestibility ($P < 0.01$) of varieties were shown to significantly improve grazing efficiency.

Keywords: *Lolium perenne* L., variety, sward characteristics, ploidy, heading date, grazing efficiency

Introduction

The production and utilisation of increased quantities of grazed grass can significantly increase the profitability of Irish dairy-farm enterprises (Dillon *et al*., 2008). Current variety evaluations are mainly focused on herbage yield and put little emphasis on herbage utilisation. It is difficult to effectively include herbage utilisation as a breeding objective. The absence of herbage utilisation from National and Recommended list evaluations, and the difficulty of assessing it on large numbers of accessions, has generally deterred breeders/evaluators from including it in their programs. Swards are known to adapt their sward structure, morphology and chemical properties in response to lower post-grazing sward height, which is a survival mechanism to escape severe defoliation and depletion of plant reserves (Briske, 1996). This creates a sward ideally suited to animal grazing, varieties are not all equally able to adapt. Post-grazing sward height has been reported as an indicator of this grazing efficiency characteristic (McCarthy *et al*., 2013). Varieties that form 'grazable' swards, i.e. swards that can be consistently grazed to a post-grazing sward height of 3.5 - 4 cm have a higher content of green leaf and digestible nutrients whilst having reduced stem and senescent material (Tuñon *et al*., 2014). Swards with this characteristic consistently support the highest percentage of herbage utilisation with no effect on sward production (McCarthy *et al*., 2013, Tuñon *et al*., 2014). The objective of this paper was to further understand the grazing efficiency of perennial ryegrass (*Lolium perenne* L.) varieties by identifying grazing traits for use as selection criteria by breeders/evaluators to develop and select varieties with improved grass utilisation.

Materials and methods

The grazing study was undertaken at Teagasc Moorepark, Fermoy, Cork, Ireland, over two grazing seasons (2015 and 2016). Fifty five perennial ryegrass varieties were examined (15 intermediate heading diploids, 10 intermediate heading tetraploids, 18 late heading diploids, 12 late heading tetraploids) which comprised both recommended and candidate varieties for the Republic of Ireland's National/Recommended list sowing 2014. The experiment was a randomised complete block design with three replicates of each variety. The plots were sown in 3 × 7 m plots in August 2014 at a rate of 31 and 40 kg ha^{-1} for diploid and tetraploid varieties, respectively. Ten sward height measurements were recorded in each plot pre- and post- grazing using a Jenquip rising plate meter. From each plot three selected herbage samples were taken for quality analysis, cut at 4 cm from grazings 2 - 7 in 2015 and 3 - 7 in 2016, and analysed for dry matter digestibility (DMD), water soluble carbohydrate (WSC) and crude protein (CP) by near infrared spectroscopy. Sward structural characteristics were measured during the reproductive (12 April to 20 June) and the vegetative (2 July to 6 September) growth phases in both years. Seventy tillers were randomly selected from each plot, cut at ground level and oven dried at 90 °C for 24 h, with 50 used to measure tiller mass and 20 tillers used to determine the proportion of leaf, true stem, pseudostem and dead material, pre-grazing extended tiller height (ETH), extended sheath height (ESH) and free leaf lamina (FLL) in the grazed horizon (above 4 cm). Tiller density was determined seasonally for each plot (March, July and November) of each year. Data were analysed using Mixed Models in SAS (SAS, 2011). Terms included in the model were variety, ploidy, heading date, block, rotation and the ploidy × heading date interaction.

Results and discussion

All parameters measured were significantly different ($P < 0.001$) between years and grazing rotation with no interaction between ploidy and heading date observed. For a trait to be considered as selection criteria it had to be influenced by variety (Table 1) and be shown to cause a significant change in post-grazing sward height in either ploidy or heading date groups and have a significant negative Pearson's correlations with post-grazing sward height. Only FLL (r^2 = -0.41), tiller mass (r^2 = -0.51) and DMD (r^2 = -0.57) met this criteria. Increased FLL was shown to significantly ($P < 0.001$) reduce post-grazing sward height across ploidy and heading dates by -0.030 cm and -0.060 cm, respectively, per unit increase. For every 1 g DM increase in tiller mass post-grazing sward height decreased by -0.054 cm and -0.098 cm within ploidy and heading date groups, respectively. For each unit increase in DMD, post-grazing sward height was reduced by -0.004 cm and -0.008 cm within ploidy and heading date groups, respectively. Pre-grazing sward height is an important factor ($P < 0.001$) as it is positively correlated with post-grazing sward height (r^2 = 0.46). The use of post-grazing sward height as an indicator of grazing efficiency is justified as it accounts for 92% of the variation in the quantity of herbage removed.

Conclusions

This study shows that varieties differ in their grazing efficiency leading to herbage utilisation differences. Ploidy and heading date influence grazing efficiency; ploidy influences a wide range of sward canopy and quality characteristics which regulate grazing. Pre-grazing sward height had a significant effect on grazing efficiency demonstrating the role management has in achieving high grass utilisation. Free leaf lamina, tiller mass and DMD were identified as reliable indicators of a variety's grazing efficiency. A combination of these parameters have the potential to deliver varieties ideally suited to grazing regimes if used as key selection criteria by plant breeders. This study shows the importance of plant and animal interactions when evaluating varieties. Future grass variety evaluations should test and publish information on a variety's grazing efficiency to provide direction to both breeder and farmer.

Table 1. Sward characteristic differences between ploidy and heading date groups under animal grazing.

Trait	Ploidy			Heading date				Variety
	D[1]	T	*P*-value	I	L	*P*-value	s.e	*P*-value
Herbage removed	5.1	5.4	***	5.3	5.2	**	0.03	***
Post-grazing characters								
Post-grazing residual (cm)	4.1	3.8	***	3.9	4.0	**	0.03	***
Extended tiller height (cm)	8.6	8.1	**	8.3	8.4	NS	0.10	**
Extended sheath height (cm)	4.5	4.2	**	4.2	4.5	*	0.15	NS
Pre-grazing characters								
Pre-grazing height (cm)	9.4	9.0	***	9.3	9.2	**	0.14	***
Morphological								
Extended tiller height (cm)	27.3	29.2	***	28.8	27.7	***	0.27	***
Extended sheath height (cm)	8.4	8.7	NS	8.9	8.2	**	0.23	*
Free leaf lamina (cm)	19.0	20.5	***	20.0	19.5	NS	0.16	***
Leaf proportion	0.66	0.67	NS	0.67	0.67	NS	0.014	NS
Pseudostem proportion	0.16	0.15	NS	0.15	0.16	NS	0.004	NS
True stem proportion	0.08	0.08	NS	0.09	0.07	**	0.006	*
Dead proportion	0.10	0.09	**	0.09	0.10	NS	0.008	*
Tiller mass (g DM^{-1})	0.06	0.08	***	0.07	0.07	NS	0.001	**
Chemical composition								
DMD (g kg^{-1} DM)	819.8	833.2	***	824.0	829.0	***	1.75	***
WSC (g kg^{-1} DM)	174.5	192.2	***	179.8	186.8	***	5.45	***
CP (g kg^{-1} DM)	176.4	178.8	**	178.3	176.8	NS	1.82	***
Sward density								
Tillers (m^{-2})	4,837	3,679	***	4,176	4,341	NS	102.0	NS
Ground score (0-9)	4.2	3.7	***	3.8	4.0	*	0.06	***

[1] D = Diploid, T = tetraploid, I = Intermediate, L = Late, NS = $P > 0.05$, * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$.

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Using genome-wide selection to increase genetic gain for forage yield in a perennial ryegrass breeding programme

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Abstract

Genetic gain in forage species has been low in comparison to other crops. Reasons include a long selection cycle, an inability to select for 'harvest index', an inability to exploit heterosis, and less investment. Indirect selection using genome-wide markers offers an opportunity to accelerate genetic gain for forage yield in perennial species by enabling multiple cycles of genomic selection (GS) to be performed in the same time it takes to perform a single cycle of conventional selection. However, in order to take advantage of GS in forage breeding we must overcome some of the challenges to its implementation and modify genotypic selection schemes to take full advantage of GS. In this paper we present results evaluating GS models for first cut silage in a tetraploid perennial ryegrass (*Lolium perenne* L.) population. Predictive abilities of between 0.19 and 0.23 for first cut silage were achieved. As multiple cycles of GS can be completed in the time it takes to complete a single cycle of conventional genotypic selection this translates to over a three-fold greater breeding gain with GS.

Keywords: *Lolium perenne* L., genomic selection, yield, forage breeding

Introduction

Accelerating the rate of genetic gain in perennial ryegrass (*Lolium perenne* L.) for traits such as forage yield, persistency and nutritional value is the focus of many forage breeding programmes. A typical progeny-based (half-sib/full-sib families) recurrent selection scheme takes five to six years from producing and evaluating families to crossing selected plants to generate an improved population. There is the potential to reduce this to a single year using DNA based selection strategies such as genomic selection (GS), thereby accelerating the rate of genetic gain in forage breeding. However, there are challenges that need to be overcome before the benefits of GS can be realised in perennial ryegrass breeding. One such challenge is the existence of limited useful linkage disequilibrium (LD) in many perennial ryegrass breeding populations. Limited LD impacts GS by requiring (1) near full genome coverage with molecular markers and (2) impractically large training populations. Strategies for applying GS in forage grasses that overcome these challenges have been proposed (Hayes *et al.,* 2013) and are based on reducing the effective population size and, thereby, increasing LD. Despite these challenges, there have been a number of promising examples of GS in forage grass breeding (Annicchiarico *et al.,* 2015; Fe *et al.,* 2016). In this study we have selected a small training population developed from a restricted base that is expected to have substantial useful LD. Parental plants were genotyped and half-sib progeny phenotyped, and the data used to evaluate GS for forage yield.

Material and methods

A late heading tetraploid perennial ryegrass cultivar with strong performance on the Irish Recommended List in 2012 was used as a starting population for further rounds of selection. This cultivar had been derived by intercrossing 75 plants from each of four full-sib families. Individual plants from this cultivar were established in a replicated polycross nursery in 2013 to produce 109 half-sib families for field-evaluation. Half-sib families were established in sward plots (6.0 × 1.5 m) in Oak Park, Carlow, Ireland in 2014. The plots were sown in two replicates and managed under a four cut silage regime. First-cut silage was harvested in 2015 (21 May) and 2016 (12 May). Plots were cut dry to touch and fresh weight recorded. Maternal plants were genotyped using a genotyping-by-sequencing approach and sequence data was aligned to the reference genome (Fe *et al.,* 2015) for variant calling as previously described (Byrne *et al.,* 2017). We used a simplified procedure for genotype calling (Li *et al.,* 2014) that did not distinguish between the three heterozygote states, which is challenging in the absence of very high sequence read depth (> 60 X). The first cut silage yields were used to evaluate GS. We evaluated various approaches for genomic prediction: (1) using genomic-BLUP based on the relationship matrix derived from the genomic data, (2) three Bayesian approaches and (3) using the ensemble learning algorithm random forest regression, which can account for correlation and interaction among variables. Genomic-BLUP was carried out with the R package rrBLUP (Endelman, 2011), Bayesian approaches (Bayes A, Bayes B, and Bayesian Lassos) were carried out with the R package BGLR (number of iterations = 5,000, burn-in = 500 and thinning = 5), and random forest regression was performed with the R package random forest (Liaw and Wiener, 2002) with the number of variables (P) at each split set to $1/3(P)$, terminal node size of 5, and 500 trees per forest. We performed Monte-Carlo cross validation by assigning 80% of the population as training with the remainder used for testing and repeated this 500 times. The mean predictive ability was determined as the average Pearson correlation coefficient between predicted and observed phenotype over all iterations. Variance components and BLUPs were determined in lmer (Bates *et al.,* 2015) and marker-based heritability with 95% confidence interval was determined with the R package Heritability (Kruijer *et al.,* 2015).

Results and discussion

The mean first cut silage yield (fresh weight) in the population was 35.17 t ha^{-1} in year one and 35.07 t ha^{-1} in year two. Repeatability (broad-sense heritability, H^2_b) for first cut silage yield was moderately high at 0.36 and a marker-based estimate of heritability (h^2_n) was determined as 0.12 (95% CI; 0.06 - 0.25). Whereas the marker-based estimates of heritability only account for additive genetic variation, the heritability in a broad-sense includes non-additive genetic variation. Importantly, the evaluation of GS in this study is focussed on predicting only the additive genetic variation (parental breeding values), ultimately reflecting how GS will be applied in forage breeding. We discovered 45,569 Single Nucleotide Polymorphisms (SNPs), genotyped each maternal plant at each SNP and collected phenotypes on the half-sib progeny. Predictive ability for first cut silage ranged between 0.19 and 0.23 depending on the predictive model with little difference between models (Table 1).

These predictive abilities are in line with results from similar studies of the perennial forage grasses alfalfa (*Medicago sativa* L.) and switchgrass (*Panicum virgatum* L.) using similarly sized training populations to evaluate forage yield (Annicchiarico *et al.,* 2015; Ramstein *et al.,* 2016). The fact that we could achieve moderate predictive accuracies for first cut silage with such a small training population and less than 50,000 SNPs is likely a result of the restricted population used in our study. The estimated extent of LD (above background levels) in this population ranged between 2.5 and 10 centimorgan depending on linkage group. Even with moderate accuracies of prediction, GS can be advantageous by enabling a cycle of selection to be performed in a much shorter time frame than conventional selection. Furthermore, as

Table 1. Predictive ability for first cut silage using different genomic selection models. The mean of 500 cross-validations is shown.

Genomic selection model	Pa[1]
Genomic BLUP	0.22
Random forest	0.22
Bayesian A	0.20
Bayesian B	0.19
Bayesian Lasso	0.23

[1] Predictive ability (mean of 500 cross validations).

genotyping costs reduce it is anticipated that much higher selection intensities can be employed, which will further improve the relative selection efficiency of GS over conventional selection. Improvements in predictive accuracies are also likely with larger reference populations and will improve over generations as LD increases and GS models are updated. Strategies to control for inbreeding in such closed recurrent selection schemes have already been proposed (Lin *et al.,* 2017).

Conclusions

The relative selection efficiency of GS over conventional selection for first cut silage yield is 3.2, assuming no degradation in predictive ability over generations and a narrow sense heritability of 0.12. The increased efficiency is being driven by our ability to complete multiple cycles of GS in the time it takes to complete a single cycle of conventional selection. These findings should encourage the implementation of GS to increase genetic gain for perennial ryegrass yield.

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White clover stolon growth characteristics under varying levels of nitrogen fertiliser

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Keywords: white clover, stolon, growth, N fertiliser

Introduction

White clover *(Trifolium repens* L.; clover) can increase the sustainability of grass-based dairy systems. The inclusion of clover in perennial ryegrass (*Lolium perenne* L.; grass) swards can increase herbage growth rates (Frame and Newbould, 1986) and maintain a higher nutritive value. Intensive grass-based systems usually rely on high nitrogen (N) fertiliser rates to ensure an adequate supply of herbage for grazing. However, many studies suggest that clover in grass/clover swards does not persist under high N levels and high stocking rates (> 2.5 LU ha^{-1}; Frame and Newbould, 1986). The objective of this study was to determine the effect of varying levels of N fertiliser on clover stolon dynamics in an intensive grazing system.

Materials and methods

The study was conducted at Teagasc, Animal and Grassland Research Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland. This experiment compared the effect of N fertiliser on white clover sward dynamics in grass/clover swards receiving 150 or 100 kg N ha^{-1} yr^{-1} (Cl150 and Cl100, respectively) in an intensive grazing system. In July 2017, 60 clover stolons in each treatment were identified and marked. Measurements included clover stolon elongation and nodal appearance measured every two weeks, and stolon width measured every two months between July and December 2017. Data were analysed using Mixed Models in SAS (SAS, 2011). Terms included in the model were N fertiliser rate, block, rotation and the N fertiliser rate × rotation.

Results and discussion

The rate of N fertiliser application had a significant effect (P < 0.05) on stolon elongation; the Cl150 treatment had a greater stolon growth rate than the Cl100 treatment (5.9 cm and 3.9 cm, respectively). The Cl150 treatment had a greater (P < 0.05) stolon length compared to the Cl100 treatment, 12.97 cm and 11.6 cm, respectively, which is contrary to Harris *et al.* (1996) who reported that N fertiliser rate did not have an effect on stolon growth at 0 and 200 kg N ha^{-1}. The Cl150 treatment had a greater number of nodes per plant compared to the Cl100 treatment, 6.1 and 4.5 nodes per plant, respectively. There was no significant effect of treatment on stolon width (0.254 cm).

Conclusions

Increasing the rate of N fertiliser application from 100 to 150 kg N ha^{-1} increased stolon elongation and nodal appearance.

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The effect of opening farm cover on early lactation milk and milk solids production

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Abstract

Grass availability in spring is highly variable. Including grazed grass in the diet of early lactation dairy cows can result in improved animal performance. The objective of this experiment was to determine if a high opening farm cover (OFC) can impact on early lactation milk production in a spring calving system. In spring 2017 (6 February – 25 April), 45 cows were randomly assigned to one of three (n = 15) OFC; High (H) (974 kg DM ha^{-1}), Medium (M) (863 kg DM ha^{-1}) and Low (L) (624 kg DM ha^{-1}). All cows were allocated an equal daily grazing area. Post-grazing sward height and daily herbage allowance (DHA) were measured daily and pre-grazing herbage mass (> 3.5 cm) twice weekly. Milk yield was recorded daily and composition once weekly. There was a significant effect of treatment on daily milk yield ($P < 0.05$); the H treatment had greater production than the M treatment (+1.9 kg cow^{-1}). Milk composition did not differ with treatment. Daily herbage allowance was greater ($P > 0.05$) on the H treatment than the L treatment, with the M treatment intermediate. Higher OFC increases grass availability on the farm which increases DHA, resulting in increased milk production performance.

Keywords: herbage allowance, pasture availability, early lactation, milk production

Introduction

The supply of feed in the form of grazed grass generally exceeds the feed demand of spring-calving dairy cows from mid-April to mid-September. There is, however, little grass growth from November to February (Dillon *et al.*, 1995), resulting in low grass availability in early spring when a significant quantity of milk is produced in spring calving milk production systems. Positive effects of including grazed grass in the diet of early lactation cows on animal and sward productivity have been reported (Kennedy *et al.*, 2007, McEvoy *et al.,* 2008). Dry matter intake (DMI) in early lactation is a critical factor influencing animal performance and increasing daily herbage allowance (DHA) can result in increased milk production (Kennedy *et al.*, 2007). The increase in DMI post calving to peak intake capacity occurs at a vulnerable period in the grazing season. As a result, it is essential to ensure adequate herbage is available to support DMI requirements until grass growth equals animal demand on farm. If grass is not available in adequate supply in early spring, concentrate supplementation is required in conjunction with grass silage to achieve similar production to cows on a high grass DHA (Kennedy *et al.,* 2005). In recent years data from Pasturebase Ireland (Hanrahan *et al.,* 2017) has shown that farms in Ireland do not have sufficient herbage amassed at turnout in spring (opening farm cover; OFC) to meet feed demand, particularly as herd size increases and this warrants an investigation into the effect of OFC on the early lactation milk production of a spring calving dairy cow.

Materials and methods

An experiment was established at Teagasc, Animal and Grassland Research Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland in 2017. Opening farm cover, the average grass available on per hectare basis on 1 February prior to the commencement of grazing, was visually quantified using the farm cover technique described by O'Donovan *et al.* (2002). A range of OFC's was established by imposing three closing management treatments during autumn 2016. A proportion of the farm was closed each day using the autumn rotation planner (Teagasc, 2009) from (1) 25 September to 9 November to achieve a high OFC (H); (2) 10 October to 24 November to achieve a medium OFC (M); and (3) 24 October to 9 December to achieve a low OFC (L). In spring (6 February – April), 45 (12 primiparous and 33 multiparous) spring calving dairy cows were selected and blocked according to calving date, lactation number, breed, pre-experimental milk production variables (day three to eight), pre-experimental body weight and body condition score and randomly assigned to one of three treatments (H, M and L) (n = 15). All treatments were stocked at 2.9 cows ha^{-1}. All cows were allocated a fixed daily area as specified by the spring rotation planner (Teagasc, 2009). Fresh pasture was allocated after each milking and on-off grazing (Kennedy *et al.*, 2011) was used as a management tool to graze in inclement weather. Pre- (PreGSH) and post-grazing sward height (PostGSH) were measured daily using a rising plate meter (Jenquip, Feilding, New Zealand). Herbage mass (> 3.5 cm; HM) was measured twice weekly by cutting two strips from each paddock to be grazed next with an Etesia mower (Etesia UK Ltd., Warwick, UK). Daily herbage allowance was calculated using the measured herbage mass and the area allocated to the cows to determine kg grass DM offered per cow. All treatment groups were offered the same quantity of concentrates per cow and the quantity fed on a daily basis was determined by the requirement of the M treatment to maintain a grazing residual ≥ 3.5 cm. All cows received a total of 215 kg concentrate over the experimental period. Silage was supplemented to an individual treatment when PostGSH dropped below 3 cm. Milk yield was recorded daily (Dairymaster, Causeway, Co. Kerry, Ireland) and milk composition (fat and protein concentrations) was measured weekly using MilkoScan 203 (DK-3400, Foss Electric, Hillerød, Denmark). Milk solids (MS) yield was calculated as the sum of milk fat and protein yield. Milk production variables were analysed using PROC MIXED in SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). Terms used in the model included treatment, breed, parity, days on experiment and pre-experimental milk production variables. Herbage variables were analysed using PROC MIXED. The terms included in the model were treatment, week and rotation.

Results and discussion

The OFC on 1 February was 974, 863 and 624 kg DM ha^{-1} for the H, M and L treatments, respectively. Treatment had a significant effect ($P < 0.05$) on daily milk yield. The H treatment had a greater daily milk yield (23.5 kg cow^{-1}) compared to M (21.6 kg cow^{-1}), with the L intermediate (22.3 kg cow^{-1}) (Table 1). There was, however, no significant effect of treatment on milk solids yield (H = 1.89, M= 1.82 and L = 1.81 kg MS cow^{-1} daily). Milk composition was similar for all treatments (fat = 47.7 g kg^{-1} and protein = 34.3 g kg^{-1}). In the current study DHA was significantly greater for the H compared to the L treatment ($P < 0.05$; +3.2 kg DM cow^{-1}). A total of 77, 89 and 99 kg silage DM cow^{-1} were offered to the H, M and L treatments, respectively. There were also significant differences in total DMI (grass + silage + concentrate) ($P < 0.05$); H had a daily intake of 16 kg DM cow^{-1} while the L had a daily DMI of 12.3 kg DM cow^{-1} and the intake of the M treatment was intermediate (14.2 kg DM cow^{-1}). Treatment had a significant effect on pre-grazing HM ($P < 0.05$), the H treatment had a pre-grazing HM of 1,355 kg DM ha^{-1} (+ 388 kg DM ha^{-1} greater than the L treatment), the pre-grazing HM of the M treatment was intermediate (1200 kg DM ha^{-1}), similar to Roche *et al.* (1996) who found significantly lower HM on late closed swards compared to early closed swards the following spring. There was no effect of treatment on PostGSH (3.79 cm).

Table 1. The effect of opening farm cover high (H) (974 kg DM ha^{-1}), medium (M) (863 kg DM ha^{-1}) and low (L) (624 kg DM ha^{-1}) on daily milk and milk solids yield, and milk composition during the experimental period (6 February to 25 April).

Treatment[1]	H	M	L	Standard error	*P*-value
Milk yield (kg cow^{-1})	23.5^{a}	21.6^{b}	22.3^{ab}	0.48	0.027
Fat (g kg^{-1})	46.9	48.8	47.5	0.11	0.435
Protein (g kg^{-1})	34.2	35.2	33.4	0.05	0.099
Milk solids yield (kg cow^{-1})	1.89	1.82	1.81	0.051	0.421

[1] Treatments within a row with the same letter are not significantly different.

Conclusions

The results of this experiment show that achieving a higher OFC in spring can support greater levels of milk production as a result of higher DHA and higher total DMI. Further investigation is required to determine the effect of OFC on total lactation production and the effect of the grassland management strategies adapted in this study on herbage production and sward characteristics.

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Pasture allowance, duration and lactation stage: effects on early lactation production

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Abstract

Spring grass availability can be a big challenge for Irish dairy farms due to limited over winter growth. The objective of this experiment was to determine the effect of pasture allowance (PA) offered for varying durations in early lactation on cumulative milk (MY) and milk solids yield (MSY), bodyweight and body condition score. Intake capacity (IC) was calculated for the control group (C) and they were offered a 100% PA. The remaining treatments were offered 60% PA for either two (×2) or six weeks (×6) from week one (E), three (M) and five (L) of experiment. All cows received 100% IC from week 11. After 10-weeks C had a greater MY than all treatments (+ 151 kg cow^{-1}). The E60 × 2 and L60 × 2 treatments had similar 10-week MSY to C (121 kg cow^{-1}), and C was higher than all other treatments (+ 11 kg cow^{-1}). Cumulative production at 33-weeks was higher for the C and E60 × 2 compared to L60 × 6. Despite immediate effects on milk production during periods of low grass availability, PA can be reduced with minimal effect on total lactation production with the exception of an extended restriction at peak milk production. However, other aspects of production need to be considered.

Keywords: pasture allowance, early lactation, dairy production

Introduction

Pasture availability in early spring can be highly variable, due to prevailing climatic conditions with many farmers experiencing short term deficits throughout the first and second grazing rotation. PastureBase Ireland data (Hanrahan *et al.,* 2017) has shown large variation in spring growth on farm, with year-to-year variation as high as 40%. Dry matter (DM) intake in early lactation is critical as cows reach peak milk production and peak DM intake; therefore, it is essential to determine the repercussions of restricting pasture during this period. Previous research has focused on supplementation strategies to overcome deficits in grass supply, however, supplementation can reduce grass utilisation (Kennedy *et al.*, 2007) and increase production cost. In recent years studies have shown that post-grazing sward height can be used as a short term tool to control pasture allowance (PA) in early lactation without impairing total lactation performance (Ganche *et al.*, 2013; Crosse *et al.*, 2015). However, PA was controlled for a period of ten weeks in these experiments with actual PA deficits unlikely to extend for this period in practical circumstances, therefore, the current experiment looked at the impact of shorter term reductions. The objective of this study was to determine the effect of reduced PA offered for varying durations at different stages in early lactation, on short term and total lactation production.

Materials and methods

The experiment was undertaken at Teagasc Moorepark, Animal and Grassland Research and Innovation Centre, Fermoy, Co. Cork, Ireland from 14 March to 31 October 2016. The experiment was a randomised block design that consisted of seven grazing treatments. A total of 105 cows (30 primiparous) were randomly assigned to each of the treatments (n = 15). Cows were balanced on breed, calving date, parity, days in milk (DIM), pre-experimental milk production, BW and BCS gathered during the two weeks prior to commencement of the experiment. The control group (C) were allocated a PA representing 100%

of their intake capacity (IC; Faverdin *et al*., 2011), which takes cognisance of parity, age, DIM, BW and BCS, diet characteristics and potential milk production amongst other factors. The remaining treatments were allocated 60% of the PA offered to the C treatment for a period of either two (×2) or six weeks (×6) from week one (E), three (M) or five (L) of the experiment. Once their respective 60% PA durations had finished, all treatments received 100% of IC. From week 11 all cows grazed as a single herd. All PA were offered above 3.5 cm; post grazing sward height was not restricted. While treatments were imposed, herds grazed separately but adjacent to one another, separated by temporary electric fences. All cows received a fresh PA after each milking until all treatments had ceased in week 11. Herbage mass (HM; > 3.5 cm) was measured twice weekly by cutting eight 10 m strips from the grazing area. Pre- and post-grazing sward height was measured on a daily basis using a rising plate meter (Jenquip Rising Plate Meter, New Zealand). Milk yield (MY) was recorded on a daily basis. Milk composition was determined weekly from one successive evening and morning milking. Fat and protein concentrations were measured using MilkoScan 203 (DK-3400, Foss Electric, Hillerød, Denmark). Bodyweight and BCS (1 to 5 scale: 1 = emaciated, 5 = extremely fat) in increments of 0.25; (Lowman *et al*., 1976) were also measured by a trained independent observer on a weekly basis. Milk and milk solids yield (MSY) were summed following the first ten weeks of the experiment and also at the end of the experiment (week 33). Bodyweight and BCS at the end of each period were also analysed. Variables associated with production were analysed using PROC MIXED models in SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). The models contained terms for treatment, breed, parity, DIM and pre-experimental production covariates. These covariates were centred within breed and parity.

Results and discussion

After ten weeks on experiment, C had significantly higher cumulative MY than all other treatments (+ 151 kg milk cow^{-1}). The E60 × 2 and M60 × 2 had similar production to E60 × 6 and M60 × 6 and L60 × 2. However, L60 × 2 produced more milk than L60 × 6 (+ 82 kg milk cow^{-1}). The L cows were at peak milk production (59 DIM, ± 11 days) at the onset of their 60% PA treatment and this may have had a greater negative impact on subsequent milk production when compared to PA reductions imposed at other stages of early lactation. The E60 × 2 and L60 × 2 treatments had similar MSY to C (121 kg MS cow^{-1}) over the ten weeks, however, the M60 × 2 treatment and all 60 × 6 PA treatments had significantly lower MSY than C (- 11 kg MS cow^{-1}; Table 1). There were similar numerical differences between all 60 × 2 treatments and their respective 60 × 6 treatments, which demonstrates that the six week reduction may have a more severe effect on MSY. Bodyweight and BCS were similar for all treatments at week ten (477 kg cow^{-1} and 2.83, respectively) and, therefore, further investigation is required regarding indicators of energy status throughout the ten weeks to determine the true effect of reduced PA on the cow. There was a tendency ($P = 0.079$) for C and E60 × 2 to have greater total MY than the L60 × 6 treatment (Figure 1). The greater loss in production observed by the L60 × 6 treatment group at ten weeks was reflected in total performance compared to C (- 416 kg cow^{-1}). There was no effect of treatment on the remaining variables analysed (323 kg MS cow^{-1}, 512 kg BW, 2.83 BCS).

Table 1. The effect of pasture allowance (60 and 100%) and duration (×2 and ×6 weeks) in early (E), mid (M) and late (L) early lactation on ten week cumulative production - milk yield (MY), milk solids yields (MSY), bodyweight (BW) and body condition score (BCS).[1]

Treatment	Control (100)	E60×2	E60×6	M60×2	M60×6	L60×2	L60×6	SE	*P*-value
MY (kg cow^{-1})	1,603^{a}	1,496^{b}	1,431^{bc}	1,468^{bc}	1,429^{bc}	1,487^{b}	1,405^{c}	22.7	0.001
MSY (kg)	124^{b}	118^{abc}	113^{ac}	114^{ac}	110^{c}	121^{ab}	116^{ac}	2.5	0.014
BW (kg)	487	476	456	488	481	472	482	15.3	0.816
BCS	2.76	2.78	2.83	2.79	2.88	2.85	2.89	0.036	0.076

[1] a-c - values not sharing common superscript are significantly different.

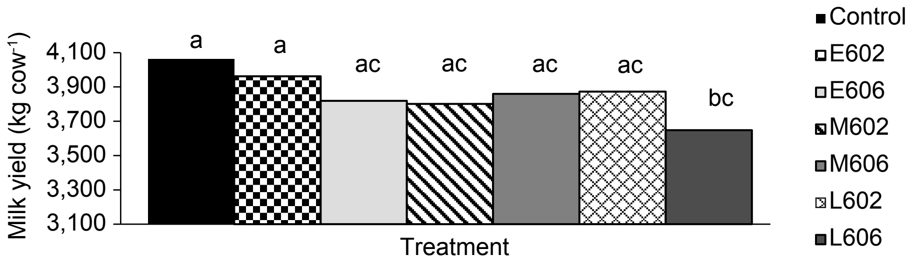

Figure 1. Total milk production for the 33-week experimental period.

Conclusions

While allocating a 60% PA can reduce MY and MSY in the short term, this study demonstrates that a greater reduction in total production occurs when PA is reduced at peak milk production. However, prior to this, reduced PA has minimal effect on total performance once PA is restored to 100% of IC. This suggests that reducing PA has the potential to become a tool to overcome short term grass deficits prior to cows reaching peak milk production. However, further investigation is required to determine the effects of such reductions on other factors influencing dairy cow production such as health, fertility and welfare.

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Breeding red clover (*Trifolium pratense* L.) for improved yield and persistence

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Abstract

Red clover (*Trifolium pratense* L.) is a tap rooted, nitrogen (N) fixating legume primarily used for silage production. It is capable of producing high yields of high quality forage resulting in greater animal intakes and higher levels of animal performance in terms of milk and protein yields than grass silage alone. Red clover is typically viewed as short term crop with a life span of about three years, with yields declining substantially over time. As such, its uptake in regions operating primarily permanent grassland-based livestock systems, such as Ireland, is low. Teagasc initiated a new red clover breeding programme in 2007 to improve the main weaknesses in red clover. This paper outlines the new breeding programme's goals, methodology and results to date. This includes a new red clover cultivar, T10108D, offering 21% higher yields and 42% higher ground cover compared to Merviot, the benchmark control cultivar, in the second harvest year of trials across Northern Ireland, Scotland and Wales. Multisite and multiyear field trials confirm that the programme has been highly effective at improving the target traits.

Keywords: *Trifolium pratense* L., yield, persistence, breeding, selection

Introduction

Red clover (*Trifolium pratense* L.) can offer considerable benefits to livestock systems. Two of the main attractions of red clover are its contribution of nitrogen (N) to grassland by fixing atmospheric N and its high nutritive value and intake characteristics for livestock. Swards with a high red clover content (e.g. 75% of 12 t DM ha^{-1} $year^{-1}$) would be expected to fix in excess of 200 kg N ha^{-1} $year^{-1}$ (Black *et al.*, 2009). The feeding value benefits of red clover in comparison with grass are due to a number of factors including faster rates of digestion and particle breakdown in the rumen, more non-ammonia N reaching the small intestine and a higher efficiency of energy utilisation. These feeding value benefits have translated to mean liveweight gains in beef cattle offered red clover silage of 1.04 kg day^{-1} compared to grass silage of 0.59 kg day^{-1} (Phelan *et al.*, 2015). Despite its considerable attractions, the use of red clover in permanent grassland-based livestock systems, which predominate in Ireland, is low. This is primarily due to yields declining significantly over time giving a short term lifespan of about three years and its poor persistence under frequent cutting and grazing. The goal of plant breeding is to create new phenotypes, improved in one or more important characteristics, in the most efficient manner possible. Recognising the significant benefits of red clover, Teagasc initiated a red clover breeding programme for the first time in 2007. The target was to improve red clover in terms of dry matter (DM) yield and persistence. This paper summarises the progress of this programme and includes trial results of a newly bred red clover cultivar.

Materials and methods

The source population for the breeding programme consisted of two commercial diploid red clover cultivars. A random sample of surviving plants was taken from sward plots of the selected cultivars which had been sown in a mixture with perennial ryegrass (*Lolium perenne* L.) and managed under a 4 cut silage system for the previous 6 years. The selected plants were subjected to phenotypic and genotypic selection. Phenotypic selection was based on recording flowering date and intercrossing in isolation later flowering plants to produce a new cultivar. Genotypic selection was based on among-and-within full-sib family selection. Full-sib families were produced by pair crossing selected plants using bumble bees as the pollinator. The full-sib families were established in a mixture with perennial ryegrass in replicated sward plots and subjected to a 4 cut silage regime for 2 harvest years. Harvest 1 was taken at early flowering (mid-May). Harvests 2 and 3 were taken at 6 weeks regrowth. Harvest 4 was taken in mid-October. Dry matter yield, persistence, disease resistance and flowering date were recorded. Selected plants were intercrossed in isolation to produce a new cultivar. One cultivar (T10108D) from the new breeding programme has to date been submitted to the UK Recommended/National List trials where it was evaluated under the UK National List protocol (Animal and Plant Health Agency, 2017) which includes replicated, multisite and multiyear monoculture trials across Northern Ireland, Scotland and Wales.

Results and discussion

T10108D was compared against two early flowering, benchmark cultivars: Merviot (diploid) and Amos (tetraploid) (Table 1). Early flowering cultivars give two similar conservation harvests and subsequent lower yield harvest(s). Late flowering cultivars give a greater proportion of their yield at the first harvest (Frame *et al.*, 1998). T10108D yielded 33 and 39% of its annual production at Harvest 1 in Harvest year 1 and 2, respectively, suggesting that selection for later flowering did not dramatically shift flowering time. Nevertheless, T10108D was certainly more persistent than the control cultivars as evidenced by substantially higher ground cover and yields at all harvests in Harvest year 2. Selection for later flowering may have positively contributed to improved persistency as later flowering cultivars tend to have more numerous growing points than early flowering cultivars (Frame *et al.*, 1998). Establishing the source population from survivors taken from a 6 year old sward may also have contributed to improved persistency. Previous studies have shown that significant selection pressures act upon the sward over time resulting in a genetic and morphological shift in the surviving population which may contribute to better agricultural fitness (Collins *et al.*, 2001). Although the yield of T10108D also declined in the second Harvest year 2, the difference in yield between Harvest year 1 and year 2 was substantially less than that of the control cultivars.

Table 1. Red clover dry matter yield and percentage ground cover from UK Recommended/National List trials (adapted from NIAB Statistics).[1]

Harvest year/cultivar	Yield (t dry matter ha^{-1})					Percentage
	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Annual	ground cover
Harvest year 1						
Merviot	5.61	4.11	2.77	1.57	12.47	50
Amos	4.83	3.99	2.94	1.50	13.16	53
T10108D	4.30	3.91	2.92	1.82	12.96	56
LSD					1.324	13.9
Harvest year 2						
Merviot	4.27	2.68	1.98	0.90	9.59	36
Amos	4.48	3.11	2.24	0.75	10.31	45
T10108D	4.77	3.36	2.82	1.31	11.59	51
LSD					2.012	12.3

[1] Harvest 1, 2, 3 and 4 yields from Aberystwyth, Wales; Annual yield and autumn ground cover score mean of Crossnacreevy, Northern Ireland, Aberdeen, Scotland and Aberystwyth, Wales; LSD = least significant difference.

Conclusions

A new red clover breeding programme targeted at improving red clover yield and persistency was established by Teagasc. Multisite and multiyear field trials confirm that the programme has been highly effective at improving the target traits with a new cultivar maintaining considerably higher yields and ground cover than the control cultivar into the second harvest year. Further genetic gains can be expected from repeated rounds of recurrent selection.

Acknowledgements

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Plant diversity greatly enhances weed suppression in intensively managed grasslands

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Abstract

Weed suppression was investigated in a field experiment across 31 international sites. The study included 15 plant communities at each site, based on two grasses and two legumes, each sown in monoculture and 11 four-species mixtures varying in the relative proportions of the four species. At each site, one grass and one legume species was selected as fast establishing and the other two species were selected for persistence. Average weed biomass in mixtures over the whole experiment was 52% less (95% confidence interval, 30 to 75%) than in the most suppressive monoculture (transgressive suppression). Transgressive suppression of weed biomass persisted over each year for each mixture. Weed biomass was consistently low and relatively similar across all mixtures and years. Average sown species biomass was greater in all mixtures than in any monoculture. The suppressive effect of sown forage species on weeds in mixtures was achieved without any herbicide use. At each site, weed biomass for almost every mixture was lower than the average across the four monocultures. The average proportion of weed biomass in mixtures was less than in the most suppressive monoculture in two thirds of sites. Mixtures outyielded monocultures, and mixture yield comprised far lower weed biomass.

Keywords: legume-grass mixtures, diversity, weed suppression, evenness, GDI model (Generalised-Diversity_interactions model)

Introduction

A major challenge to agroecosystems is to increase agricultural production to meet an increased demand for food production (Lüscher *et al.,* 2014) while sustaining the environment and flexibly adapting to climate change. The use of multi-species mixtures (plant diversity) in intensively managed systems has been proposed as one strategy to improve agricultural sustainability. Plant diversity potentially provides a substitute for many costly agricultural inputs (Isbell *et al.,* 2017). Here we focus on the use of plant diversity to suppress weed biomass in intensively managed grasslands. Uncontrolled weed growth can represent a major source of inefficiency, diverting nutrients, water, light and labour to an undesirable form of biomass, while herbicide use incurs significant environmental and economic costs. In pastures, weeds can impair forage quantity and quality resulting in reduced animal production, and increase the need for reseeding with its consequent costs. If diversity helps in maintaining a low level of weeds in pastures (and increases yield) it can increase the sustainable production of higher quality forage compared to systems relying on monocultures.

Using data from the 31-site Agrodiversity field experiment (Kirwan *et al.,* 2014) which used four-species mixtures (two grasses and two legumes), we addressed the following questions:

1. Do monocultures of grassland species differ in their suppression of weeds?
2. Are weeds transgressively suppressed by mixtures of grassland species? (Weed biomass in mixture being less than weed biomass in the most suppressive monoculture.)
3. Is weed suppression by mixtures affected by differences in species' relative abundance?
4. Is variation in weed biomass less in mixtures than in monocultures?

Materials and methods

We conducted a co-ordinated continental-scale field experiment across 31sites to investigate these questions. At each site the study included 11 four-species mixtures, varying in the relative proportions of two grass and two legume species. The four species were also sown in monoculture. The four species used were not the same at all sites, at each site species were selected that suited local conditions, the two grasses being selected from non-fixing grasses *Dactylis glomerata* L., *Festuca arundinaca*, *Lolium perenne* L., *Lolium rigidum* L., *Phleum pratense* L., *Poa pratensis* L. and the two legumes from N_2-fixing species, *Trifolium repens* L., *Trifolium pratense* L., *Trifolium ambiguum* L., *Medicago sativa* L., *Medicago polymorpha* L. At each site, one grass and one legume species was selected as fast establishing (G_F and L_F) and the other two species were selected for persistence (G_P and L_P). Mixtures were designed to reduce reliance on fertiliser nitrogen. We first summarised information on the suppression of weed biomass across the 15 communities for each of the three years and across years. We tested at each site for transgressive suppression of weeds. To address questions 1 to 4 we used a version of diversity interactions modelling (Connolly *et al.*, 2013). This uses a mixed model to relate weed biomass per plot to sown proportions of each of the four species and also includes a diversity effect to estimate the effect of various mixtures on weed yield.

Results and discussion

Previously, we showed strong effects of plant diversity in enhancing total biomass, biomass of sown species and N capture across the 11 four-species grass-legume mixtures (Finn *et al.*, 2013; Suter *et al.*, 2015). Here, we summarise results from Connolly *et al.* (2017) showing similar strong effects of mixtures on weed suppression in the same experiment.

Averaged across all sites, weed biomass in mixtures over the whole experiment was 52% less (95% confidence interval 30 to 75%) than in the most suppressive monoculture (transgressive suppression). Transgressive suppression of weed biomass persisted over time, being found in each year for each mixture (which varied in sown composition between 20% to 80% grass). Weed biomass was consistently low and relatively similar across all mixtures and years (Figure 1(a)). Harvested biomass of sown species (weeds excluded) was much greater in mixtures (Figure 1(b), Finn *et al.*, 2013) and total biomass had less weeds. Within a site, weed biomass varied much less in mixtures than in monocultures.

Across sites, the growth conditions differed remarkably from Mediterranean (Spain, Sardinia) to sub-Arctic (Iceland, north Norway). Yet, at each site the weed biomass for almost every mixture was lower than the average weed biomass across the four monocultures. The average proportion of weed biomass in mixtures was less than in the most suppressive monoculture in two thirds of sites. Transgressive suppression of weeds was maintained across years and was independent of site productivity. Mechanisms behind these results are discussed in Connolly *et al.* (2017).

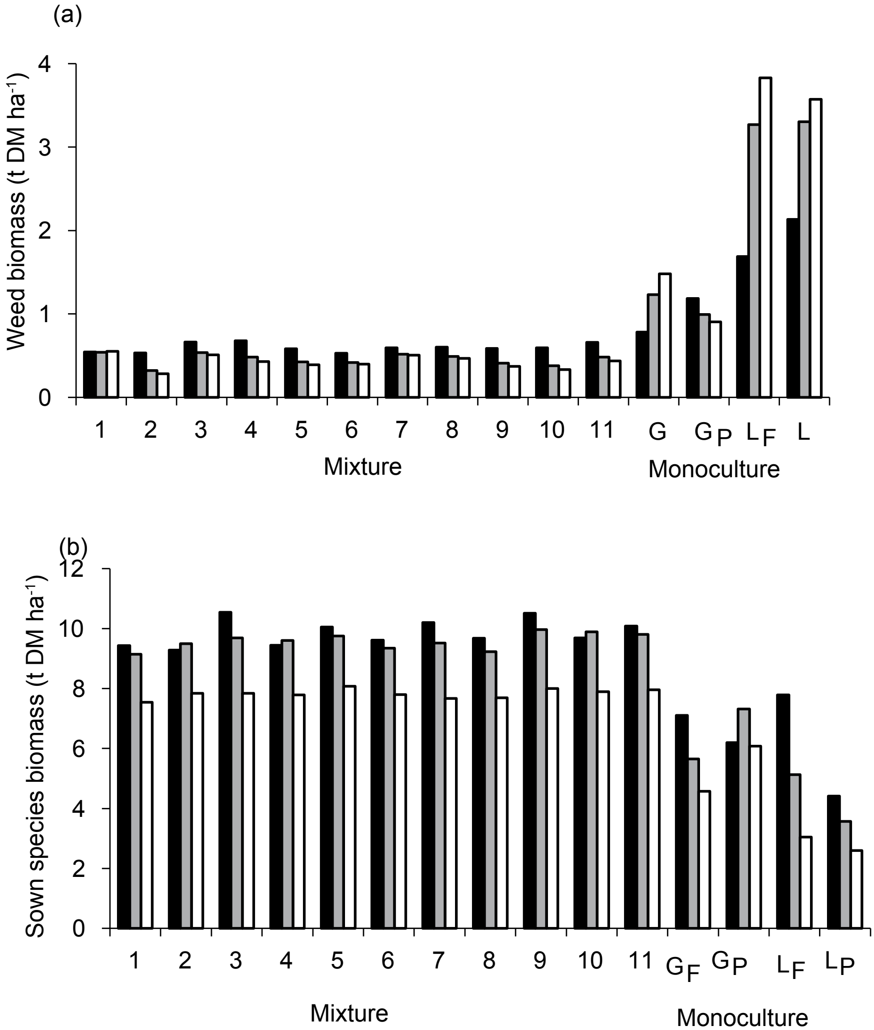

Figure 1. Annual weed biomass and sown species biomass (t DM ha^{-1}) for each mixture (1 to 11) and for each monoculture (a fast establishing grass (G_F), a persistent grass (G_P), a fast establishing legume (L_F) and a persistent legume (L_P) for each of three years; (a) weed biomass values predicted from Generalised-Diversity_interactions model, (b) total biomass averaged over sown densities and sites.

Conclusions

Weed invasion can be diminished through combining forage species selected for complementarity and persistence traits in systems designed to reduce reliance on fertiliser nitrogen. In this study, total harvested biomass from mixtures was not only much greater (Figure 1(b), Finn *et al*., 2013) but also comprised far less weeds. The effects of diversity on weed suppression were consistently strong across mixtures that varied widely in species proportions and over time. The level of weed biomass did not vary greatly across mixtures that varied widely in proportions of sown species. These findings suggest that the composition of the mixtures need not be tightly controlled either at sowing or subsequently, making the system easier to manage. We conclude that these diversity benefits of weed suppression, which occurred in parallel with increased forage yields and nitrogen capture in intensively managed grasslands, are relevant for the sustainable intensification of agriculture and are achievable through practical farm-scale actions.

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Phosphorus yield of forage grass species under intensive cutting management

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Abstract

Soils in Europe that are used for intensive dairy and meat production generally contain more phosphorus (P) than needed to maintain high yields. To prevent losses of P from agricultural soils to the environment, the use of manure is legally restricted. In Flanders (Northern Belgium), the use of manure is limited, or even prohibited, on soils with a high P concentration. On these soils, crops with a high P yield are desired, in order to partly mine out the plant available soil P pool. In a three year field trial, the DM yield and foliar nitrogen (N) and P concentrations of tall fescue (*Festuca arundinacea* Schreb.), perennial ryegrass (*Lolium perenne* L.) and *Festulolium* were compared under an intensive cutting management. Although tall fescue was the species with the lowest P concentration in the foliage (3.66 g P kg DM^{-1}), its high yield (14,173 kg DM ha^{-1}) resulted in the highest P yield of 51.9 kg P ha^{-1}, compared to 47.4 kg P ha^{-1} and 42.3 kg P ha^{-1} for perennial ryegrass and *Festulolium* respectively. However, the advantage of tall fescue compared to the other species to mine out soils proved to be modest.

Keywords: tall fescue, *Festulolium*, perennial ryegrass, P leaching, nitrogen use efficiency

Introduction

In many regions of the world, soil phosphorus (P) deficiency restricts crop yields severely. Tropical and subtropical soils are predominantly acidic and often extremely P deficient with high P-sorption (fixation) capacities (FAO, 2004). In several regions of North-West Europe, on the other hand, the soils are saturated with P, particularly in regions with intensive livestock production and/or sandy soils. In these regions, P losses from agricultural land threaten biodiversity as well as several ecosystem functions such as the provisioning of clean water. This accumulation of P in the soils originates from an imbalance between the import of nutrients through concentrates and fertiliser and the export through milk and/or meat on livestock farms. In a study of 255 representative dairy farms, on different soil types in the Netherlands, farm gate surpluses of 269 kg N ha^{-1} yr^{-1} and 18.9 kg P ha^{-1} yr^{-1} were found in the period 1998-2000 (Aarts *et al*., 2005). To tackle the environmental problems associated with P loss towards the environment, national and European legislation is restricting the use of manure on soils where the P concentration is above a certain threshold. Due to the legally restricted low supply of manure, the supply of other nutrients (nitrogen (N), potassium (K), magnesium (Mg)) decreases and forces the farmers to apply expensive mineral (N, K) fertilisers. In Flanders, for instance, the soils are classified in five classes according to their soil P concentration (P extracted with ammonium lactate corresponds to the plant available P in the soil) with a corresponding P fertilisation limit for each class: e.g. grassland soils in class II ('optimal content'; between 190 and 250 mg P kg^{-1} dry soil) can receive up to 38.7 kg P ha^{-1} whereas on soils in class IV ('high content'; more than 500 mg P kg^{-1} dry soil) P fertilisation is restricted to 30.1 kg P ha^{-1}. Hence, farmers are keen to grow crops with a high P yield which can eventually lower the P content of the soil and thus allow a higher use of manure. The aim of this study was to evaluate the P yield potential of the grass species tall fescue (*Festuca arundinacea* Schreb.), perennial ryegrass (*Lolium perenne* L.) and *Festulolium* and to evaluate their potential to eventually mine out the soil.

Materials and methods

A field plot trial, comparing two single varieties of three different grass species (tall fescue (*Festuca arundinacea Schreb*.), perennial ryegrass (*Lolium perenne* L.) and *Festulolium*) under an intensive cutting management, was sown in the spring of 2011 on a sandy loam soil in Merelbeke (50° 59'N, 3° 47' E), on the experimental fields of ILVO. Individual plots measured 8.4 m^2 and were sown in three replicates. The soil had a pH-KCl of 5.7, contained 1.12% of soil organic carbon and 160 mg P-AL kg^{-1} dry soil. Between 2012 and 2015, five cuts were harvested annually. Fertilisation amounted to 300 kg N ha^{-1} yr^{-1} and 205 kg K ha^{-1} yr^{-1}. As the P concentration of the experimental field was just below optimal for grasses, there was no P fertilisation. In 2015, a representative variety for each species ('Barolex' for tall fescue, 'Meloni' for perennial ryegrass and 'Lifema' for *Festulolium*) were sampled at each cut. The plant material was dried and analysed for P content. Biomass P-concentrations were obtained after digesting 100 mg of each sample with 0.4 ml $HClO_4$ (65%) and 2 ml HNO_3 (70%) in Teflon bombs for 4 h at 140 °C. Phosphorus was measured calorimetrically according to the malachite green procedure (Lajtha *et al*., 1999). The P yield for the three varieties were calculated for each cut by multiplying P concentration with herbage production, and compared using one-way analysis of variance in R. Multiple comparisons of means was done with the *TukeyHSD* function in R.

Results and discussion

In the fourth production year of the swards (2015), the dry matter yield of tall fescue was 20% greater than that of perennial ryegrass (Table 1), which is in accordance with earlier studies (Cougnon *et al*., 2013). Although the P concentration of tall fescue was lower than that of *Festulolium* and perennial ryegrass, the greater yield of tall fescue resulted in a significantly greater P yield for tall fescue (Table 1). The capacity of tall fescue to extract more nutrients from the soil can be explained by its deeper rooting and greater root biomass, particularly at greater depths, compared to perennial ryegrass and *Festulolium*. Cougnon *et al*. (2017) found that, in a trial on the same soil and under a similar management as the present study, the ratio between the root biomass of tall fescue and that of the mean of the other species in the study (perennial ryegrass, *Festulolium* and meadow fescue (*Festuca pratensis* L.)) increased from 1.41 in the 5 - 15 cm layer to 5.82 in the 75 - 90 cm layer of the soil.

Although the P yield of tall fescue is greater than that of perennial ryegrass, the practical implications to mine out soils are rather restricted. Imagine one wants to lower the P concentration in the soil layer 0 - 30 cm from 300 mg P kg^{-1} soil (class III) to 200 mg P kg^{-1} soil (class II). In a soil with a bulk density of 1,450 kg m^{-3}, 435 kg P ha^{-1} should be extracted from the soil to obtain the desired reduction. With the yields obtained in this study, it would take nine and ten growing seasons for tall fescue and perennial ryegrass to reach this threshold, respectively. In reality, it will take even longer as some P is also extracted from deeper soil layers. In addition, while the pool of plant available P is depleted, there will

Table 1. Dry matter yield, Phosphorous (P) yield and the P concentrations of three forage grass species grown in 2015.[1]

Species	Yield kg DM ha^{-1}	P yield kg P ha^{-1}	P concentration g kg^{-1}
Perennial ryegrass	11,887^{bc}	47.4^{ab}	0.0399^{a}
Tall fescue	14,173^{a}	51.9^{a}	0.0366^{b}
Festulolium	10,962^{c}	42.3^{b}	0.0386^{ab}
Significance	***	**	**

[1] The significance of the species effect on these parameters is indicated in the last row as: ** $P \leq 0.01$, *** $P \leq 0.001$. Values in the same column with a different letter are statistically different.

be redistribution from other more stable P sources to the labile, plant available, pool which slows down the decrease of the labile pool (De Schrijver *et al*., 2012). Hence, the advantage of growing tall fescue compared to perennial ryegrass to mine out the soil P pool is restricted.

Conclusion

The P yield of tall fescue was 9.0% greater than that of perennial ryegrass and 22.6% greater than that of *Festulolium*. Hence, tall fescue is a better candidate to mine out soil P than perennial ryegrass or *Festulolium*, although the differences in mining capacity are modest.

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Fatty acids concentrations in forage species during growing season in Iceland

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Abstract

Composition of fatty acids in forage species can affect the fatty acid profile of meat and dairy products. The aim of this study was to quantify the concentrations of fatty acids of five forage species; timothy (*Phleum pratense* L.), tall fescue (*Festuca Arundinacea* Schreb.), perennial ryegrass (*Lolium perenne* L.), red clover (*Trifolium pratense* L.) and white clover (*Trifolium repens* L.) four times during the growing season for two years in south-west Iceland. The concentrations of fatty acids varied with phenological stage during the growing season, with the greatest value of total fatty acids in the spring, reduced levels in July and increasing levels towards the end of the season. There were also significant differences in fatty acid concentrations between years and between species, but no interaction with year. α-linolenic (18:3*n*-3), linoleic (18:2*n*-6) and palmitic (16:0) acids were the predominant fatty acids in all species. The omega-3 fatty acid, 18:3*n*-3, was the most abundant and accounted for most of the variation. Red clover had the highest concentration of total fatty acids and 18:3*n*-3.

Keywords: phenological stage, timothy, perennial ryegrass, tall fescue, red clover, white clover

Introduction

As a consequence of biohydrogenation in the rumen, ruminant fat is usually high in saturated fatty acids. Plants are the main source of 18:2*n-6* and 18:3*n-3* in the food chain because humans and animals lack the ability to introduce double bonds beyond the 9th carbon. The major fatty acids in the cell membranes of plants are stearic acid (18:0), oleic acid (18:1*n-9*), linoleic acid (18:2*n-6*), α-linolenic acid (18:3*n-3*), palmitic (16:0), palmitoleic (16:1*n-7*) and palmitolenic (16:3*n-3*). Production of fatty acids is affected by various environmental factors in addition to management strategies (Arvidsson *et al.*, 2013). Cabiddu *et al.* (2009) showed that polyunsaturated fatty acids (PUFA) in forage vary seasonally and the seasonal pattern of fatty acid composition seems to be mostly related to the phenological stage of the plants. PUFAs are high in spring and early summer, then decrease and increase again in autumn; however, there are significant differences between species (Boufaïed *et al.*, 2003; Cabiddu *et al.*, 2009). Consequently, composition of fatty acids in forage species can affect the fatty acid profile of meat and dairy products. Nudda *et al.* (2005) found that the composition of milk fat in sheep's milk is seasonal and mainly dependent on fatty acid composition of grazing crops. Similarly, Mel´uchová *et al.* (2008) found the same seasonal variations in CLA content in sheep's milk fat and the same has been found in bovine milk fat (Kalač and Samková, 2010). The aim of this study was to measure how the fatty acid content of forage species changed throughout the growing season.

Materials and methods

A field experiment with three replicate plots was established in spring 2005 at the experimental station Korpa (64° 09' N) to compare the fatty acid composition of forage species. The experimental plots were cut twice, in early July and middle of August. Plots were fertilised with 120 kg nitrogen (N) ha^{-1} in spring and 60 kg N ha^{-1} after first harvest each year. Mean temperature was 6, 11.2, 13.5 and 11 °C in May, June, July and August, respectively, in 2007 and 8.9, 11.1, 12.8, 11.5 °C, respectively, in 2008. To measure the fatty acid concentration, above ground samples were collected from five species; timothy (*Phleum pratense* L.; cv. Adda), tall fescue (*Festuca Arundinacea* Schreb.; cv. Norild), perennial ryegrass

(*Lolium perenne* L.; LøRa9401 from Norway), red clover (*Trifolium pratense* L.; cv. Betty) and white clover (*Trifolium repens* L.; cv. Norstar). Samples were taken four times during the growing season, at the beginning of the months of June, July, August and September in 2007 and 2008. Experimental fields were harvested after the second and third sampling; therefore, samples in August and September were from regrowth. For each sample, approximately 50 g of above ground growth was immediately wrapped in aluminium foil and frozen in liquid N. The samples were then freeze-dried and ground in a ball mill. Fatty acid concentrations were analysed by gas chromatography on one sample for each variety at each sampling date. Extraction of fatty acids was performed according to Browse *et al.* (1986). ANOVA was performed by Genstat v13.3 with species and measure date as factors and year as repeated measurements.

Results and discussion

All species showed seasonal variations in total fatty acid content and the content of 18:3*n*-3, with highest values in the spring, reduced values in July when plants were at a mature phenological stage and increasing values towards the end of the season when sampling from regrowth (Table 1). The results support earlier

Table 1. Fatty acid composition of five fodder species, total saturated fatty acids (SFA), total unsaturated fatty acids (PUFA), mg g^{-1} DM, and the ratio of unsaturated and saturated fatty acids, average of two years.

	16:0	16:1	18:0	18:1	18:2	18:3	Total	SFA	PUFA	PUFA:SFA
Timothy. Adda										
1 June	4.07	0.73	0.30	0.51	1.94	4.45	12.24	4.75	6.38	1.36
1 July	2.84	0.60	0.23	0.46	0.97	2.09	8.00	3.52	3.38	0.98
1 August	3.82	1.68	0.24	0.29	1.26	3.17	11.71	4.56	5.18	1.14
1 September	3.48	1.54	0.24	0.29	1.48	3.92	12.02	4.22	5.96	1.41
Tall fescue. Norild										
1 June	4.07	0.67	0.18	0.61	1.71	7.78	15.35	4.51	9.54	2.04
1 July	3.15	0.69	0.12	0.50	1.01	4.06	10.11	3.51	5.38	1.52
1 August	3.94	1.25	0.16	0.37	1.20	5.17	12.89	4.41	6.85	1.55
1 September	4.52	1.53	0.23	0.41	1.39	5.47	14.62	5.24	7.44	1.45
Ryegrass. LøRa9401										
1 June	4.39	0.95	0.29	0.55	1.29	3.82	12.03	4.93	5.58	1.12
1 July	3.13	0.71	0.22	0.43	0.63	1.88	7.73	3.62	2.95	0.82
1 August	3.67	1.06	0.24	0.30	0.86	3.02	9.99	4.25	4.37	1.01
1 September	4.09	1.46	0.28	0.27	0.65	2.32	10.25	4.81	3.69	0.77
Red clover. Betty										
1 June	4.98	1.02	0.43	0.74	4.25	13.13	25.33	6.06	17.51	2.89
1 July	4.76	0.80	0.43	0.32	4.26	10.40	21.71	5.67	14.79	2.61
1 August	4.79	1.32	0.58	0.49	3.46	13.51	24.99	6.00	17.13	2.85
1 September	5.20	1.63	0.42	0.44	3.65	12.23	24.69	6.33	16.17	2.56
White clover. Norstar										
1 June	5.62	1.24	0.43	0.75	2.86	10.00	21.90	6.68	13.19	1.97
1 July	5.48	1.20	0.46	0.64	2.66	8.84	20.33	6.52	11.94	1.83
1 August	5.68	1.37	0.49	0.57	2.48	9.88	21.60	6.83	12.83	1.88
1 September	6.07	1.72	0.46	0.47	2.73	9.68	22.43	7.24	12.98	1.81
Species	***	*	***	*	***	***	***	***	***	***
Measure date	***	***	*	**	**	**	**	***	**	ns
Date × Species	ns	ns	**	ns	ns	ns	ns	ns	ns	ns
S.e.d. Species	0.145	0.094	0.017	0.073	0.153	0.652	0.889	0.154	0.720	0.128
S.e.d. Date	0.130	0.084	0.015	0.065	0.137	0.583	0.795	0.147	0.644	0.114
S.e.d. Date × Species	0.291	0.188	0.033	0.145	0.306	1.303	1.777	0.328	1.440	0.255

studies of Boufaïed *et al*. (2003), Mel´uchová *et al*. (2008) and Cabiddu *et al*. (2009) showing different seasonal patterns of the fatty acid profile throughout the growing season related to the phenological stage of the plant. It was warmer in 2008 than in 2007; this was reflected in a generally higher content of PUFA in 2008, but with no interaction between years. Therefore, the two years are used as repeated measurements in the data analysis. Results are similar to Boufaïed *et al*. (2003) and Mel´uchová *et al*. (2008), with seasonal variations in fatty acids primarily related to variations in 18:3*n*-3, with 18:3*n*-3, 16:0 and 18:2*n*-6 the most abundant fatty acids. Legumes (red and white clover) had the highest total fatty acids, 18:3*n*-3 and the highest ratio of PUFA:SFA. Red clover, which had the highest 18:3*n*-3 content in this study, is known to increase the levels of 18:3*n*-3 acid in cow's milk (Dewhurst *et al*., 2003) when cows are fed with clover silage. Interestingly, lambs grazing red clover produced meat with higher proportions of 18:2*n*-6 and 18:3*n*-3 compared with lambs grazing perennial ryegrass (Fraser *et al*., 2004).

Conclusions

Seasonal variations in fatty acid concentrations, together with differences between species, indicate that the ruminant's total intake of fatty acids, especially 18:3*n*-3, can be increased by managing grazing strategies. Red clover had the highest quantity of fatty acids. Grazing cultivated clover mixture fields can be a worthy option to increase the fatty acid content, particularly omega-3 in the diet of livestock. Grazing in spring or at an early phenological stage may also increase PUFA intake of livestock. The study also demonstrates the effect of climatic variations on fatty acid content reflected in the variation between years.

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Combining grazing and high mineral efficiency

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Abstract

In the Netherlands many farmers assume pasture grazing for dairy cows to be less efficient in terms of mineral utilisation than indoor housing systems. The gross annual grass yield is assumed to be lower as well. Since 2016, Dutch dairy farmers are obliged to use the ANCA-tool (Annual Nutrient Cycling Assessment) to show the mineral efficiency of their farms. Farmers claim that pasture grazing leads to a worse ANCA performance than indoor housing. This claim puts pressure on pasture grazing. Therefore, a study was performed to analyse the effect of grazing on mineral efficiency. The analysis of a dataset containing 2,725 ANCA results of Dutch dairy farms showed that the average phosphorus and nitrogen excretion for farms that apply pasture grazing for their cows for less than 1000 hours cow^{-1} yr^{-1} were not significantly different from the indoor housing systems. On farms that apply grazing for more than that, the mineral excretion was higher. Measures were identified to improve the mineral efficiency, e.g. less young stock, feeding additional roughage and concentrate low in protein and phosphorus. This study shows that farms with restricted grazing can combine grazing and mineral efficiency.

Keywords: ANCA, excretion, grazing, nitrogen, phosphorus, mineral efficiency

Introduction

The environmental impact of nutrient losses from dairy farms is an area of concern as farms increase in herd size and stocking rates. Dairy farmers in the Netherlands are allowed to apply more manure on their farm if they can prove that the average excretion of nitrogen (N) and phosphorus (P) per cow is below the general excretion standards set by the government. For this purpose, the Annual Nutrient Cycling Assessment (ANCA) tool (Aarts *et al.,* 2015), which is compulsory for all dairy farms, was used. It calculates the nutrient efficiency, excretion of N and P at farm level, N and P yields in crops and the complete N, P and carbon cycle at farm level. Harvested feed, grazing hours and purchased feeds are basic inputs required to calculate the mineral cycles. Many dairy farmers assume that pasture grazing leads to low calculated nutrient efficiencies causing higher N and P losses compared to indoor housing. The gross annual grass yield of grazing is assumed to be lower as well. These assumptions lead to negative perceptions of grazing by farmers. This study aimed to analyse the effect of grazing on mineral efficiency using the ANCA tool.

Materials and methods

In this study 2,725 ANCA results from Dutch dairy farms spread over the Netherlands were collected from the years 2013 and 2014. The farms were divided into six groups based on the hours grazing cow^{-1} yr^{-1} (Table 1). The effect of grazing on mineral efficiency was tested using a one-way Anova test and a Tukey post hoc test in SPSS version 24.

Results and discussion

Restricted grazing up to 1000 hours cow^{-1} yr^{-1} did not affect excretion of N and P t^{-1} milk produced compared with indoor housing (Table 2). The excretion for grazing categories with more than 1000 hours grazing cow^{-1} yr^{-1} was significantly higher. This is at least caused by the high N and P content of grazed grass. The effect size (Eta-squared) of grazing category on excretion was 0.133 for both N and P (Table 3), which indicates that the level of mineral excretion was affected by other factors as well. Measures were identified to improve the mineral efficiency. Promising measures were less young stock, feeding additional roughage and concentrate low in N and P.

Table 1. Grazing groups and corresponding number of dairy farms in each group.

Grazing hours (cow^{-1} yr^{-1})	Number of dairy farms
0 (indoor housing)	847
1-720	501
721-1000	361
1001-1,500	596
1,501-2,000	207
> 2,000	213

Table 2. Average excretion per pasture grazing category.

Grazing h cow^{-1} y^{-1}	N (kg ton^{-1} milk produced)	Homogeneous groups*	P_2O_5 excretion (kg ton^{-1} milk produced)	Homogeneous groups*
0 (indoor housing)	16.69	A	5.67	A
1-720	16.48	A	5.65	A
721-1000	16.65	A	5.74	A
1,001-1,500	17.35	B	5.98	B
1,501-2,000	18.66	C	6.42	C
>2,000	19.42	D	6.87	D

* Different groups are significantly ($P < 0.05$) different from each other.

Table 3. Effect size of pasture grazing (hours cow^{-1} yr^{-1} on excretion).

Effect size	Nitrogen excretion (kg ton^{-1} milk produced)	Phosphate excretion (kg ton^{-1} milk produced)
Eta-squared	0.133	0.133

Conclusion

This study shows that farms with restricted grazing can combine grazing and mineral efficiency. The average N and P excretion for farms that applied grazing for less than 1000 hours cow^{-1} yr^{-1} were not significantly different from indoor housing systems.

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Forage yield in a mixture composed by grasses with different growth strategies

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Abstract

Pastures composed of species belonging to different niches are better able to capture resources and maximise their forage yield. This work aimed to test the central hypothesis that dominant perennial grasses with different growth strategies can coexist and be productive in intensively managed environments. Populations of *Arrhenatherum elatius* L. (exploitative), *Festuca arundinacea* Schreb. (conservative), and *Dactylis glomerata* L. (moderately exploitative) were evaluated as monocultures or mixtures for two years. Fertilisation was performed to maintain high levels of soil fertility and the pastures were defoliated when grasses reached a height of 20 cm to a residue of 10 cm. The proportion of the three species in the mixture remained unaltered throughout the experimental period. Although no transgressive overyielding was observed, the mixture produced the same forage yield as the most productive monoculture, even with 68.1% of its post-cut biomass being composed of *Dactylis glomerata* L., the monoculture with the lowest forage yield. Moreover, overyielding was more influenced by leaf production. The results presented here show that a mixture of temperate perennial grasses with different growth strategies is persistent, productive and can increase leaf production when grown in fertile environments and subjected to frequent and lenient defoliations.

Keywords: complementarity, intercropping, monocultures, overyielding, leaf production

Introduction

Grasslands have been treated as multifunctional ecosystems, the functions of which may be improved by increased biodiversity (Pasari *et al.,* 2013) due to complementarity between species belonging to different functional groups. According to Roscher *et al.* (2007), the complementarity in mixtures composed of dominant species becomes saturated with few species (three in that case) and, furthermore, species with different growth strategies (conservative vs exploitative) can coexist in fertile environments (Gross *et al.,* 2007), mainly when grazed (Borer *et al.,* 2014). Moreover, cut or grazing management strategies based on light interception criteria (or corresponding to pasture height), which prevent the sward from intercepting more than 95% of the incident radiation, have been observed to efficiently minimise stem elongation and maximise leaf production (Da Silva *et al.*, 2015). When the pre-grazing targets are associated with moderate/lenient grazing intensity (proportions of defoliation lower than 50% of the initial pre-grazing height) high herbage intake rates is ensured (Mezzalira *et al.,* 2014). Thus, this work aimed to test the main hypothesis that dominant perennial grasses of different growth strategies can coexist and be productive in fertile environments and be subjected to frequent and lenient defoliations.

Materials and methods

The experimental area was divided into 12 plots of 45 m^2 (5 × 9 m). Monocultures of *Arrhenatherum elatius* L. 'SCS314 Santa Vitória' (exploitative; *A. elatius*), *Festuca arundinacea* Schreb. 'Quantum II' (conservative; *F. arundinacea*), *Dactylis glomerata* L. 'Ambar' (moderately exploitative; *D. glomerata*) and a mixture of these species were repeated three times and evaluated for two years from May 2014 to June 2016. The four pastures were sown at a seed rate of 15 kg ha^{-1}. The cuts were performed when the pastures reached 20 cm in height (pre-cutting height), and were cut to 10 cm. The pre-cut height corresponded to the average canopy condition that intercepts 95% of the incident radiation during the full vegetative development stage. After soil analyses, phosphorus and potassium were applied each autumn to maintain a highly fertile environment, and nitrogen fertilisation was performed every 40 days as urea, with the application of 30 kg N ha^{-1} (270 kg N ha^{-1} y^{-1}) during the first experimental year (2014/2015), and 50 kg N ha^{-1} (450 kg N ha^{-1} y^{-1}) during the second experimental year (2015/2016). Forage net yield, as well as the yield of leaves and stems of each species, was calculated as the difference between the current pre-cutting biomass and the previous post-cutting biomass in two frames (70 cm × 20 cm) per plot. Overyielding was determined for the community and populations of each species and its parts (leaves and stems) as proportional deviations from the expected yield (and), according to Loreau (1998). Forage net yield was subjected to analysis of variance including the effects of treatment, season, year and their interactions. Averages were compared using the Tukey test at $P < 0.05$. Relationships between total and plant parts for each species were determined using Reduced Major Axis (RMA) regression.

Results and discussion

The highest forage net yields were observed for *F. arundinacea, A. elatius* and the mixture, which were similar and the lowest were observed for *D. glomerata* (Figure 1). In the mixture, *D. glomerata* was the species present in the highest proportion, making up 61.3% of the pre-cutting biomass, whereas *A. elatius* and *F. arundinacea* were present in equal proportions, each making up 18.6% of the pre-cutting biomass. It is probable that the more prostrate growth habit observed for *D. glomerata* allowed it to occupy a larger area during pasture establishment. There were no effects of treatment × season or treatment × year interactions ($P > 0.05$) on forage net yield.

Overyielding from *A. elatius* in all seasons (of 0.76, 0.72, 0.84, and 0.99 from winter, spring, summer and autumn, respectively) and from *F. arundinacea* in spring and summer (of 0.69 and 1.04, respectively) were responsible for the total mixture overyielding (Figure 2). Leaf was the main determinant of total in the three species because of the low stem yield, which made up 19.6, 5.1, and 6.5% of forage net yield for *A. elatius*, *F. arundinacea*, and *D. glomerata*, respectively.

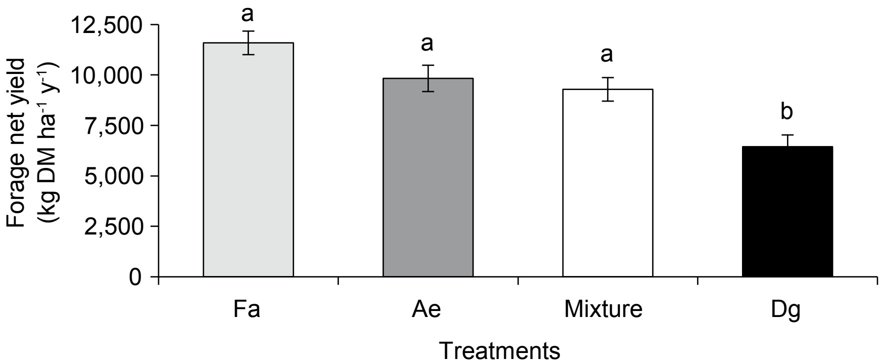

Figure 1. Forage net yield of pastures of *Festuca arundinacea* Schreb. (Fa), *Arrhenatherum elatius* L. (Ae), and *Dactylis glomerata* L. (Dg), grown in monoculture or in a mixture. Data are the means of three replicates over two years (n = 6).

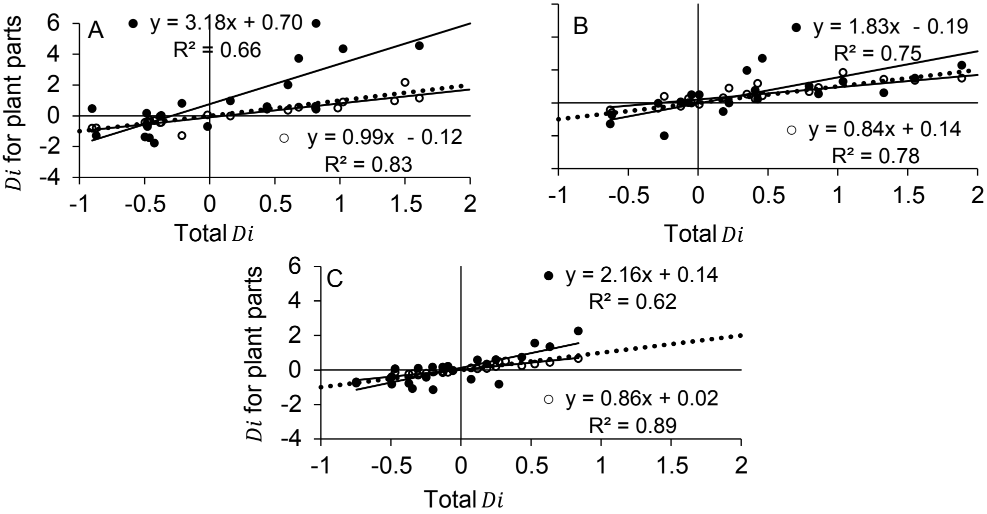

Figure 2. Reduced major axis (RMA) regressions between total and for leaves (empty circles) and stems (filled circles) of populations of (A) *Festuca arundinacea* Schreb., (B) *Arrhenatherum elatius* L., and *Dactylis glomerata* L. (C) grown in a mixture. Circles are values for each plot and season. The dotted line represents a 1:1 ratio.

Conclusions

The present results show that the establishment of mixtures of grass species with different growth strategies in fertile environments and subjected to cuttings that decrease light competition is productive, persistent and may favour pasture leaf production.

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Is the growth strategy of perennial grasses linked to their persistence pathway?

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Abstract

It is hypothesized that the growth strategy of perennial grasses determines their persistence pathway regardless of neighbouring species. Thus, species with contrasting growth strategies (*Arrhenatherum elatius* L., *Dactylis glomerata* L. and *Festuca arundinacea* L.) were evaluated as both monocultures and in a three-species mixture for two years in an intensively managed environment. Plants in all four treatments were stable throughout the experimental period. Overall, *A. elatius* had the highest rates of mortality and tiller appearance and *F. arundinacea* had the lowest. *A. elatius* produced a large number of tillers across all seasons, but the longevity of the tillers was the lowest among the three studied species. *F. arundinacea* and *D. glomerata* had numerous cohorts of tillers that were produced only during autumn-winter, but the half-lives of their tillers were six and three times longer than that of *A. elatius* tillers, respectively. No differences were observed in the tillering dynamics of the three species in monoculture or in mixed swards. The results suggest that competitive perennial grasses (like *A. elatius*) exhibit a high turnover of tillers throughout the year and, therefore, their persistence is dependent on regular favourable tillering conditions (water and input of nutrients), while more conservative species (like *F. arundinacea*) demand large amounts of resources at specific times of the year to re-establish their populations.

Keywords: conservative species, exploitative species, tiller survival, tiller appearance, tillering dynamics

Introduction

The ability of a pasture to maintain its tiller population over time is directly related to its persistence. In a review, Matthew *et al.* (2013) identified different tillering dynamics for ten forage grass species and highlighted that pasture persistence occurs due to two factors: high tiller birth rates (TBRs) and high tiller survival rates (TSRs) over time. According to Cruz *et al.* (2002), grassland species, including various C3 plants (Pontes *et al.*, 2012), can be classified into different 'functional types' depending on their growth strategies. Consequently, the most exploitative species have a greater ability to use available resources and renew their tissues than do more conservative ones, and, therefore, they have a greater number of axillary buds capable of generating new tillers (Davies, 1974). Therefore, we hypothesized that under intensive management (i.e. reduction of resource competition), population stability and, consequently, persistence of perennial grasses occurs through distinct mechanisms depending on the growth strategy of the plants, regardless of the composition of neighbouring species. Therefore, pastures with exploitative species are more dependent on a high number of tillers throughout the year than those formed by more conservative species.

Materials and methods

The experimental area was divided into 12 plots of 45 m^2 (5 × 9 m). Monocultures of *A. elatius* cv. SCS314 Santa Vitória (exploitative), *F. arundinacea* cv. Quantum II (conservative), and *D. glomerata* cv. Ambar (intermediate) and a mixture of these species sown in the same proportions were replicated three times on 13 June 2013. Treatments were randomly assigned to plots. The four pastures were sown at a rate of 15 kg ha^{-1}. When the pastures reached 20 cm in height (pre-cutting height), they were cut to 10 cm (post-cutting height, defoliation intensity of 50%), and all cut material was removed from the plots. Phosphorus (P) and potassium (K) were applied (after soil analysis) each autumn to maintain a highly fertile environment, and nitrogen (N) fertiliser was applied every 40 days as urea at a rate of 30 kg N ha^{-1} (270 kg N ha^{-1} y^{-1}) during the first experimental year (2014-2015) and 50 kg N ha^{-1} (450 kg N ha^{-1} y^{-1}) during the second experimental year (2015-2016). Tiller population dynamics were evaluated in two 20-cm-diameter polyvinyl chloride (PVC) rings (0.0314 m^2) per plot. 22 tiller cohort evaluations were carried out from June 2014 until July 2016 in which tillers were identified as alive, emerged or dead. The population stability index (PSI) was calculated according to Matthew and Sackville-Hamilton (2011), and the half-life of tillers was calculated according to Korte (1986). Tiller death rate (TDR), TBR, TSR, PSI, half-life of tillers and the total number of emerged tillers were calculated by seasons. Means were estimated using LSMEANS and differences between them were compared with Tukey's test at a 5% significance level.

Results and discussion

Arrhenatherum elatius developed cohorts with many tillers (more than 3,000 tillers m^{-2}) in all seasons. On the other hand, *F. arundinacea* and *D. glomerata* produced numerous cohorts mainly during autumn and winter (Figure 1).

The proportion of *D. glomerata*, *A. elatius*, and *F. arundinacea* tillers in the mixture treatment were 52.4, 24.3 and 23.0%, respectively. The highest and lowest TDR and TBR occurred in *A. elatius* and *F. arundinacea*, respectively, but *A. elatius* tillers exhibited the lowest longevity, whereas *F. arundinacea* tillers had the highest (half-life of 41 and 231 days, respectively, $P < 0.001$). This result could be a response to the high tissue flow that has been observed in more exploitative species (Cruz *et al.*, 2002) and, consequently, the number of buds available to develop new tillers (Davies, 1974). Comparing seasonal patterns within the year, *A. elatius*, *D. glomerata*, and the mixture had the highest TDR during the spring and summer, whereas in *F. arundinacea*, the rates were constant throughout the year. Population recovery in *A. elatius* began in summer while recovery in *F. arundinacea*, *D. glomerata*, and the mixture only started in autumn. These results are similar to those of Ryle (1964) who found a negative relationship between temperature and tillering in C_3 species. However, this response pattern was less obvious in *A. elatius*, which kept young tillers available for sward recovery after defoliation even during unfavourable conditions (e.g. warmest season for C_3 species). This characteristic is generally observed in exploitative

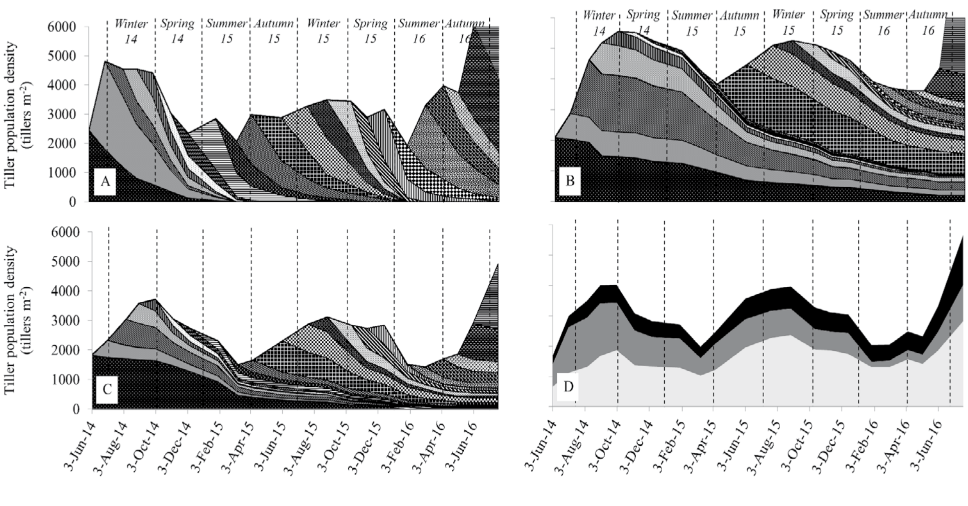

Figure 1. Tillering dynamics of *Arrhenatherum elatius* (A), *Festuca arundinacea* (B) and *Dactylis glomerata* (C) populations sown in monoculture or a three-species mixture (*A. elatius*, grey; *F. arundinacea*, black; *D. glomerata*, white) (D) throughout the experimental period. Different fill patterns in the monoculture diagrams (A-C) represent tiller population density from each of the 22 tiller cohorts.

species (Nelson, 2000). As a consequence, the *A. elatius* population was unstable only in spring, whereas the other treatments showed slight population instabilities during both spring and summer. No effects of cultivation method (monoculture or mixture) or the interaction of cultivation method × season on TDR and TBR were observed in the three studied species ($P > 0.05$). Thus, cultivation method did not affect the PSI of the *A. elatius*, *F. arundinacea* and *D. glomerata* populations (mean values of 1.04 (SEM = 0.023, $P = 0.2580$), 1.07 (SEM = 0.021, $P = 0.6099$) and 1.06 (SEM = 0.016, $P = 0.5071$), respectively).

Conclusions

Our study indicated that exploitative perennial grasses express high tiller turnover throughout the year and, therefore, are constantly dependent on favourable conditions (e.g. water and input of nutrients) for tillering to persist. However, although conservative species have longer-lived tillers, they demand a greater amount of resources at specific times to re-establish their tiller population. Moreover, under intensive management, the characteristics of neighbouring species do not affect the tillering dynamics of the target species.

Acknowledgements

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The agronomic and biodiversity value of semi-natural grassland types under different grazing management

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Abstract

Traditional grazing regimes are likely to be the most effective and sustainable way to maintain the rich biodiversity of semi-natural grasslands within Annex I priority farmland habitats on the Aran Islands. A key question for the sustainable management of Aran pasturelands is does the available forage resource alone meet livestock nutritional requirements? We investigated the seasonal variability of forage mineral status, nutritional quality, annual aboveground net primary production, grassland utilisation and botanical composition on representative grasslands on 25 farms across the three Aran Islands over two years. Multivariate analysis identified two principal grassland communities: winter-grazed pastures and summer-grazed pastures. Forage quality parameters exhibited community-dependant seasonal variation (e.g. crude protein ranged from 5 to 23% DM), and forage types were seasonally deficient in phosphorus, copper, zinc, selenium and cobalt. Yields ranged from 508 to 5,256 kg DM ha^{-1} $year^{-1}$, and sward species-richness ranged from 11 to 43 plants per 4 m^2. Results suggest mineral imbalances and deficiencies affect Aran forages, and winter-grazed forages alone do not meet the nutritional requirements of the suckler cow. This knowledge will be used to develop an optimal-grazing management model that promotes biodiversity and sustains livestock production on semi-natural grasslands.

Keywords: calcareous grasslands, forage quality, forage production, AranLIFE

Introduction

The agricultural landscape of the Aran Islands is largely a mosaic of rare Annex I European farmland habitat types of high conservation value – limestone pavement, orchid-rich calcareous grassland and machair; 75% of total land area (4,500 ha) is designated as Natura 2000 under European legislation. Typical farm holdings are relatively small-scale with below national average stocking rates (< 0.5 LU ha^{-1}), and contain an exceptionally high proportion of semi-natural grasslands. Grazing is essential for the conservation management of these semi-natural calcareous grasslands. However, it is not known if the forages meet the nutritional requirements of livestock. The objective of this study was to determine the production potential within these grazing systems and ascertain whether the forages meet livestock nutritional requirements. Information will be used to develop optimal grazing (for biodiversity) and supplementary feeding management guidelines that ensure habitats are managed for biodiversity and production outputs. This study is part of the larger EU LIFE-funded AranLIFE project (2014 to 2018).

Materials and methods

Forage quality sampling was performed on 50 randomly selected sites, i.e. two land parcels from 25 farms across the three Aran Islands (Inis Mór, Inis Meáin and Inis Oírr). Forages were collected from homogeneous stands of vegetation over ten sampling dates between March 2015 and January 2017 and analysed for DM, nitrogen (N; Dumas method), crude protein (CP) (N × 6.25), ash, acid detergent fibre (ADF), and neutral detergent fibre (NDF) (Van Soest *et al.*, 1991) at the Agri-Food and Biosciences Institute, Northern Ireland. In addition, 76 forage samples were analysed for dietary minerals, i.e.

phosphorus, magnesium, calcium, sodium, potassium, chloride, manganese, copper, zinc, selenium, cobalt and iodine (Inductively Coupled Plasma – Mass Spectrometry), during May 2015 and January 2016. Annual above-ground net primary production (ANPP) was quantified as kg DM ha^{-1} per annum using the moveable cage (1 × 1 × 0.4 m) method (Mc Naughton *et al.,* 1996), across nine representative sites. Forages were cut to ground level within a 0.5 × 0.5 m quadrat and oven-dried to constant weight (60 °C for 48 h) to determine percentage DM. Botanical surveys were carried out between June and July 2016 using national methodologies (O'Neill *et al.,* 2013). Non-metric multidimensional scaling ordination and hierarchical, agglomerative, polythetic cluster analysis (PC-ORD vers. 4; Euclidean relative distance measure and Ward's linkage method) was used to identify vegetation types (McCune and Grace, 2011).

Results and discussion

The main management activity within semi-natural grassland habitats was grazing and spring-calving suckler cow/drystock herd was the prevalent farm enterprise. Grazing systems on the Aran Islands can be decribed as 'reverse transhumance' agriculture; livestock graze the relatively more exposed pastures on the south side of islands from November to April, and once spring-calving commences, herds are moved to sheltered fields to the north from mid-April to October. Reflecting management trends, multivariate analysis identified two vegetation types. For the purpose of this paper they are called 'winter-grazed pastures' (WGP) and 'summer-grazed pastures' (SGP). Summer-grazed pastures had low to moderate plant species-richness and higher ANPP (Table 1). The production potential of SGP enables repeat (two to three) rotational grazing between April and October. In contrast to SGP, WGP had the highest levels of plant species-richness and lower ANPP. In general, WGP are grazed once after the growing season - a practice that it likely to promote the higher plant species-richness found in this grassland type.

There is a clear trend of declining CP concentrations in WGP from May onwards (Figure 1), with the lowest feeding value (indicated by lower CP and higher ADF concentrations) recorded between November and March. The feeding value of winter forages reach an annual low in March when cows are typically well into the last trimester of gestation and nutritional demands are highest. Mineral analyses data indicate that Aran forages are seasonally deficient throughout the year in P, Cu, Se and Co (National Research Council, 2000). Mineral supplementation is required to reduce the likelihood of mineral deficiencies arising in the herd.

Table 1. Mean (SEM) of species richness per 4 m^2, annual dry matter (DM) yields and forage quality variables for broad vegetation types on the Aran Islands.

Grassland types (sites)	Summer-grazed pasture (18)	Winter-grazed pasture (38)
Species no. (per 4 m^2)	21 (0.6)**	34 (0.4)**
Yield (kg DM ha^{-1} $annum^{-1}$)	5,580 (941)** (4)	1,760 (420)** (5)
Dry matter (g kg^{-1})	227.0 (10.8)**	381.3 (17.6)**
Crude protein (g kg^{-1} DM)	153.1 (7.2)**	100.3 (3.5)**
Acid detergent fibre (g kg^{-1} DM)	307.7 (7.1)**	324.5 (11.7)**
Phosphorous (%)	0.28 (0.01)	0.12 (0.007)
Selenium (mg kg^{-1})	0.08 (0.01)	0.11 (0.007)
Cobalt (mg kg^{-1})	0.05 (0.02)	0.02 (0.002)
Copper (mg kg^{-1})	7.65 (0.4)	5.30 (0.18)

***$P < 0.01$* = Significant differences between grassland types.

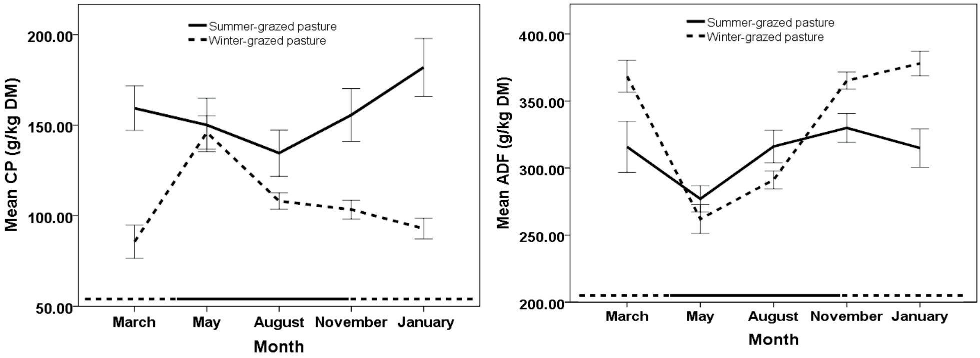

Figure 1. Seasonal changes to (a) crude protein (CP) and (b) acid detergent fibre levels (ADF) in winter-grazed pasture and summer-grazed pasture. Error bars: ± 2 SE. Horizontal line (bottom) indicates main grazing period for each pasture type.

Conclusions

The semi-natural calcareous grasslands sampled throughout this study are priority Annex I habitats for conservation under the EU Habitats Directive and are dependent on grazing for their survival. However, results from this study indicate that the grazing potential of pastures with the highest species-richness, i.e. WGP, do not fully meet nutritional demands of livestock – especially when cows are in late stages of pregnancy. The grazing management system that has been developed by farmers on the Aran Islands to best suit the forage supply throughout the year involves a cyclic pattern of loss and gain (cows gain weight on SGP when forage quantity is abundant and quality is high and slowly lose weight on WGP when forage quantity is limited and quality is low). This management system exploits compensatory growth on SGP and minimises supplementary feed costs but depends on optimum management of suckler cow energy reserves throughout the year so that compensatory gain after restriction and reproductive efficiency (e.g. timely estrus) is not negatively affected. From this work, nutritional advice can be tailored to suit the grazing system by identifying times when additional appropriate supplementary feeds may be required, thereby maximising livestock production within grazing systems that maintain high plant diversity.

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Use of plant-wax fatty alcohols and *n*-alkanes as faecal markers to predict diet selection and intake for dairy cows grazing mixed grass/clover swards

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Abstract

The objective of this research was to investigate the most appropriate method of diet selection for mixed perennial ryegrass (PRG)/white clover (clover) swards – *n*-alkane or long-chain fatty alcohols (LCOH). A data set consisting of *n*-alkane and LCOH concentrations of PRG and clover fractions was used from previous PRG intake studies. There were two grazing treatments, PRG/clover with 150 kg N ha^{-1} y^{-1} (Cl150) and PRG/clover with 250 kg N ha^{-1} y^{-1} (Cl250). The sward clover content for the Cl150 and Cl250 was 326 ± 13.1 and 212 ± 12.3g kg^{-1} DM, respectively. The *n*-alkane method indicated that selected diet clover content was 237 and 161 g kg^{-1} DM, for the Cl150 and Cl250, respectively. The LCOH method indicated that selected diet clover content was 300 and 203 g kg^{-1} DM for the Cl150 and Cl250 treatments, respectively. It is concluded that diet selection from animals grazing mixed PRG/clover swards can be quantified. Both the LCOH and *n*-alkane methodology allow for individual diet selection to be investigated, however, the LCOH method indicated a greater proportion of the diet consumed by grazing animals was clover compared to the *n*-alkane method, which was closer to the measured clover content in the sward.

Keywords: diet selection, long-chain fatty alcohols, *n*-alkane

Introduction

White clover (*Trifolium repens* L.; clover) has a higher nutritional quality than perennial ryegrass (*Lolium perenne* L.; PRG), and mixed PRG / clover swards can increase dairy cow voluntary DM intake (DMI) compared to PRG only swards (Egan *et al*., 2017). Grazing animals have the option to select their diet from a sward and many factors can influence diet selection (Rutter *et al.,* 2004). The forage selected by grazing animals is usually of a higher quality than the forage being offered (Minson, 1990), and in mixed PRG / clover swards, clover is usually preferred over PRG (Rutter *et al*., 2004). The scope for diet selection depends on the heterogeneity of the sward from which the grazing animal is feeding and the spatial distribution of different plant components (Fraser *et al.,* 2006). This study was designed to compare the use of *n*-alkane technique and the plant-wax long-chain fatty alcohol markers (LCOH) when estimating diet selection of dairy cows offered mixed PRG/clover swards.

Materials and methods

A grazing experiment was established at Teagasc, Animal and Grassland Research Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland. This experiment compared herbage and milk production from a mixed PRG/clover sward receiving 250 kg N ha^{-1} y^{-1} (Cl250) or 150 kg N ha^{-1} y^{-1} (Cl150) (Egan *et al*., 2015). Sward clover proportion was determined prior to grazing by hand separating plucked samples into PRG and clover fractions and determining DM proportions as described by Egan *et al*. (2017). Individual DM intake (DMI; n = 40) was measured using the *n*-alkane technique (Mayes *et al.,* 1986) as modified by Dillon and Stakelum (1989). Sample periods were May 2015 (measurement period 1 (MP1)) and August 2015 (measurement period 2 (MP2)). All cows were orally dosed twice daily, after milking, for twelve consecutive days with paper pellets (cellucotton stoppers, Carl Roth GmbH, Karlesruhe, Germany) containing approximately 500 mg of dotriacontane (C_{32} *n*- alkane). From day seven to 12 of dosing, faecal samples were collected from each cow twice daily, before morning and evening milking. On days six to 11 of each dosing period, two herbage samples of approximately 15 individual PRG snips were manually collected with a Gardena hand shear mimicking the grazing defoliation pattern observed on previously grazed swards. Diet selection was measured by taking additional herbage samples from the Cl250 and Cl150 treatments and manually separating into approximately 100 g each of fresh PRG and clover. The concentrations of n-alkane and LCOH were measured for the grass and clover samples individually and were used in the calculation of diet selection. The PRG/clover ratio consumed was estimated from the concentrations of the odd-chain *n*-alkanes (C27, C29, C31 and C33) and using even-chain LCOH (C24, C26, C28 and C30) separately, using an iterative routine (Microsoft Excel Solver) that calculates the DMI of PRG and clover required to produce 1 kg DM of faeces. The iterative routine minimises the sum of squares of the discrepancy between the observed individual *n*-alkane and/or LCOH faecal concentrations, using faecal recovery rates based on (Ferreira *et al.*, 2015) and expected individual faecal *n*-alkane and LCOH concentrations calculated from the *n*-alkane and LCOH concentration of the individual PRG and clover forage components. The proportions of PRG and clover in the individual cows' diets were calculated from the outputs from the iterative routine. Total forage DMI was determined using the conventional *n*-alkane technique using the estimated diet selection of each cow from the *n*-alkane and LCOH methodology for diet selection and the alkane concentrations in relevant separated PRG and clover fractions to calculate the C32 and C33 alkane contents of the total consumed diet. Data were analysed using a mixed model and Proc Reg in SAS with terms for treatment, method, measurement period and the associated interactions. Data are presented as least square means ± standard error.

Results and discussion

Grazing treatment had a significant effect ($P < 0.001$) on sward clover content. The Cl150 treatment had a greater sward clover content compared to the Cl250 treatment, (326 ± 13.1 and 212 ± 12.3 g kg^{-1} DM, respectively). Previous research has shown that *n*-alkanes and LCOH can be used successfully to determine diet selection (Fraser *et al.*, 2006) in hill PRG mixtures containing a wide range of vegetation species. The current study was determining diet selection of two species (PRG and clover). Methodology used had a significant effect ($P < 0.001$) on the estimation of the diet selected by the grazing animals (Table 1). The LCOH method indicated that a greater proportion of the diet consumed by grazing animals was clover compared to the *n*-alkane method for the Cl150 treatment (300 ± 6.6 and 237 ± 7.1 g kg^{-1} DM, respectively) and Cl250 treatment (203 ± 7.0 and 161 ± 7.2 g kg^{-1} DM, respectively). Accuracy of diet-composition estimates varied ($P < 0.05$) between methods, with the LCOH presenting a higher accuracy (0.971) compared to the *n*-alkane (0.913). When the methods were compared with the measured sward clover content (i.e. the hand separations pre-grazing), the LCOH method predicted clover content more closely to that of the actual clover content present in the sward, compared with the *n*-alkane method (Table 1). The DMI of clover and total diet estimated using LCOH diet selection markers were significantly higher ($P < 0.001$) than the values obtained using only *n*-alkanes as diet selection markers (Table 1). The combination of LCOH with *n*-alkanes produced the best estimates of diet composition and DMI when compared to *n*-alkanes alone, similar to (Ferreira *et al.*, 2015).

Table 1. The use of the *n*-alkanes and long-chain fatty alcohols (LCOH) as markers for determining diet selection in dairy cows on a mixed perennial ryegrass/white clover sward (PRG/clover) receiving 150 kg N ha^{-1} yr^{-1} (Cl150) and a PRG/clover sward receiving 250 kg N ha^{-1} yr^{-1} (Cl250). Data are mean values for measurement period 1 (May 2015) and 2 (August 2015).

	***n*-Alkane**		**LCOH**			***P*-Value**	
	Cl150	**Cl250**	**Cl150**	**Cl250**	**SE**	**Treatment**	**Method**
Measured sward clover[1] proportion (g kg^{-1} DM)	326	212	326	212	12.3	0.001	-
Selected clover content (g kg^{-1} DM)	237	161	300	203	7.5	0.001	0.001
Total DMI[2] (kg DM d^{-1})	15.5	16.2	16.6	16.9	0.43	NS	0.001
Clover DMI (kg DM d^{-1})	3.6	2.6	4.9	3.4	0.21	0.01	0.001

[1] Clover – white clover.

[2] DMI – Dry matter intake.

Conclusions

The results of this study show that diet selection and DMI from animals grazing mixed PRG/clover swards can be quantified. Both the LCOH and *n*-alkane methodology allow for individual diet selection to be investigated, however, the LCOH method indicated a greater proportion of the diet consumed by grazing animals was clover compared to the *n*-alkane method, which was closer to the measured clover content in the sward. The combination of LCOH with *n*-alkanes allows for a more accurate measurement of diet selection and herbage DMI on mixed swards.

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The effect of autumn closing date of pasture on spring herbage availability and sward characteristics

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Abstract

Previous studies have shown that grazed grass is the cheapest feed available for pasture-based systems of milk production and can make a major contribution to the diet of lactating dairy cows. The objective of this study was to examine the effect of autumn closing date on over winter herbage production and sward characteristics. There were three autumn closing managements: Early (25 September – 9 November), Normal (10 October – 24 November) and Late (25 October – 9 December). Over winter herbage mass (kg DM ha^{-1}) and perennial ryegrass (*Lolium perenne* L.) tiller density (plants m^{-2}) were measured on four and two occasions, respectively, between December and early February. Delaying the closing date in the autumn significantly ($P < 0.01$) reduced the availability of herbage in early February. Daily over winter growth rates were lower ($P < 0.05$) on the Late closed treatment compared to both the Early and Normal (4.5 and 7.5 kg DM ha^{-1} day^{-1}, respectively). Every one day delay in closing from 25 September to 9 December reduced spring herbage availability by 16.3 kg DM ha^{-1} d^{-1}. Perennial ryegrass tiller density was not significantly affected by the closing date. In conclusion, earlier closing of swards in autumn can increase over winter growth rates and spring herbage availability.

Keywords: grass growth, perennial ryegrass, tiller density, autumn closing

Introduction

Grazed grass is the cheapest source of forage for ruminant production systems in Ireland (Finneran *et al.*, 2012), and increasing its proportion in ruminant diets can reduce the total costs of production (Dillon *et al.*, 2005). In spring calving dairy systems in Ireland the supply of feed in the form of grazed grass generally matches or exceeds demand from mid-April to mid-September (Dillon *et al.*, 1995). However, grass production and utilization are restricted by climatic conditions in autumn and winter (Herrmann *et al.*, 2005). The growth of perennial ryegrass (PRG; *Lolium perenne* L.) during the winter period is characterised by a reduction in leaf appearance rate and an increase in the leaf senescence rate (Hennessy *et al.*, 2008) due to low soil and air temperatures (Parsons and Chapman, 2000) and low levels of solar radiation. As a result, the net herbage accumulation during the winter is low. The management of grass swards during the preceding autumn is crucial for ensuring the availability of grass during the spring period (Carton *et al.*, 1988; Hennessy *et al.*, 2006). The objective of this experiment was to investigate the effect of altering autumn closing date on over winter herbage production and sward characteristics.

Materials and methods

The experiment took place at Teagasc, Animal and Grassland Research Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland in 2016 and 2017. Forty-eight paddocks were established and randomly assigned to one of three autumn closing strategies (n = 16); Early (25 September - 9 November), Normal (10 October - 24 November) and Late (25 October - 9 December). Swards were grazed in rotation by 90 (n = 30) spring calving lactating dairy cows on each treatment. Herbage was allocated to cows on a daily basis based on available herbage mass (> 4 cm) to achieve a target post-grazing sward height of 4 cm. Post-grazing sward heights were measured daily using a rising plate meter (Jenquip, Feilding, New Zealand). Herbage mass (> 4 cm; HM) was determined in each paddock on 9 December, 30 December, 20 January and 10 February using an Etesia mower (Etesia UK Ltd., Warwick, UK). Over winter growth rates (kg DM ha^{-1}) were calculated from the change in herbage mass between each measurement period.

The proportions of leaf, stem and dead material of PRG tillers were measured in February 2017. A sample of PRG tillers were taken at random locations across a 'W' transect, cut to ground level using a blade, and a 40-g subsample was then dissected into the green leaf lamina, stem and dead components 4 cm above ground level. The components were sorted, weighed and dried for 16 h at 90 °C for DM determination. 160 turves (10 per paddock) (10 cm × 10 cm) were removed at random from each treatment on two occasions (15 December and 19 January) to estimate PRG tiller density. The PRG tillers in each turve were separated and counted, as described by Jewiss (1993). Data were analysed using PROC MIXED in SAS with terms for treatment, measurement period and the associated interaction. Fixed terms were treatment and measurement period, and random terms were paddock.

Results and discussion

In the current study herbage mass generally increased over the winter period, however, the rate of increase varied depending on the closing treatment. Daily over winter growth rates were lower ($P < 0.05$) on the Late (4.5 kg DM ha^{-1} d^{-1}) closed treatment compared to both the Normal and Early treatments (7.5 and 7.9 kg DM ha^{-1} d^{-1}, respectively). The lower over winter growth rates resulted in a significant ($P <$ 0.01) reduction in herbage mass in February. In the current experiment each day delay in closing from 25 September to 9 December resulted in a reduction in herbage mass in February of 16.3 kg DM ha^{-1} d^{-1} (Figure 1). The reduction in spring herbage mass due to delayed closing date observed in the current study is similar to O'Donovan *et al.* (2002) who found a reduction of 15.0 kg DM ha^{-1} for each day delay in autumn closing, while Roche *et al.* (1996) and Carton *et al.* (1988) found a reduction of 13.5 and 11.8 kg DM ha^{-1}, respectively. In the current study, delaying the autumn closing date resulted in a significantly ($P < 0.05$) higher proportion of green leaf in the sward in February on the Late (0.77 g kg^{-1} DM) closing treatment compared to both the Normal and Early treatments, 0.68 and 0.69 g kg^{-1} DM, respectively, similar to Ryan *et al.* (2010). Additionally, the Late closing treatment tended ($P = 0.57$) to have a lower proportion of dead material compared to the Normal and Early treatments, 0.09, 0.12 and 0.13 g kg^{-1} DM, respectively. Perennial ryegrass tiller density was not significantly affected ($P > 0.05$) by closing date in the current study, similar to Ryan *et al.* (2010). Perennial ryegrass tiller density increased ($P < 0.01$) over the winter period, from 2418 plants m^{-2} in December to 3102 plants m^{-2} in January.

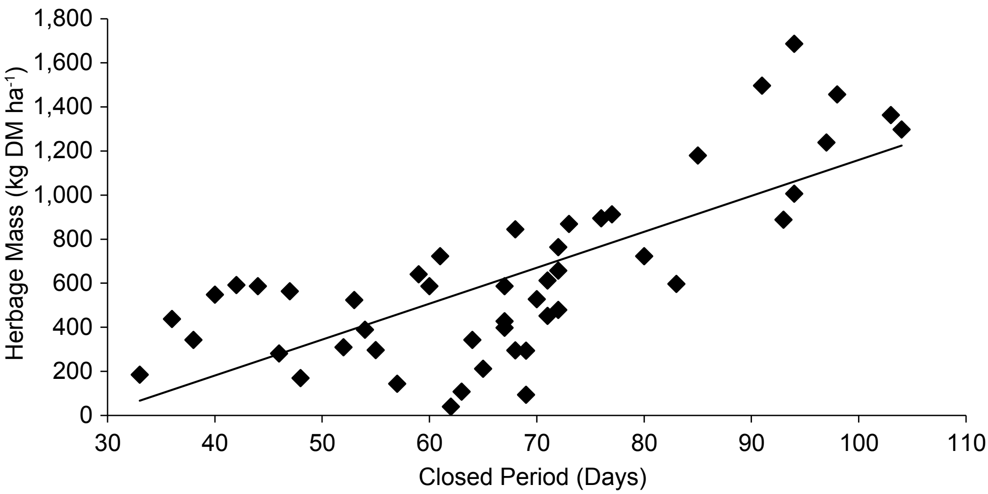

Figure 1. The relationship between autumn closing date and spring (early February) herbage mass (kg DM ha^{-1}). The relationship is described by the equation $y = 16.307x - 471.18$, $R^2 = 0.5504$.

Conclusions

Earlier closing of swards in autumn resulted in increased herbage mass the following February. Delaying autumn closing date reduced herbage mass by 16.3 kg DM ha^{-1} day^{-1} in February. Green leaf content was greatest in the Late closed swards. The overall net extra herbage in spring can provide a significant saving in alternative feeds in a spring calving system. The results from this study are from one year and the experiment will be continued for a number of years.

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Herbage mineral contents in grass and legume species

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Abstract

Herbage minerals affect the performance of grazing and grass-fed cattle. In silages, knowledge of herbage minerals is needed to balance supplements in indoor feeding rations. Herbage phosphurous (P), calcium (Ca), magnesium (Mg) and potassium (K) contents in four grasses and four legumes were investigated in binary grass-legume mixtures under a silage cutting regime. Data were collected in May and August during two harvest years in replicated plots. Herbage samples were hand-separated and individual species were analysed. The contents of Ca and Mg were higher in legumes than in grasses, but grasses had higher P and K contents than legumes. Differences were found among legume and grass species in contents of P, Ca and Mg; only legumes differed in K content. Outcomes are discussed in relation to cattle nutrition requirements and options for designing grassland mixtures for sustainable agricultural systems.

Keywords: mineral, grass, legume, animal requirement

Introduction

In ruminant diets, herbage is an important natural source of minerals. Knowledge about the mineral content of grassland species at silage cuts during the season is needed to balance supplements in indoor feeding rations in order to meet the requirements of livestock production. Information on the mineral content of grass-legume mixtures is limited. Therefore, a field experiment was conducted on a sandy soil with seven two-species forage mixtures sown in replicated plots; annual yields and nutritive values were reported by Elgersma and Søegaard (2016). The aim of this experiment was to study macromineral contents of grasses and legumes, grown in mixtures, in spring and summer. The hypothesis of this experiment was that mineral contents would differ among species and between functional groups, i.e. grasses and legumes.

Materials and methods

Perennial ryegrass (*Lolium perenne* L.; 'PR') was sown with each of four forage legumes: red clover (*Trifolium pratense* L.; 'RC'), lucerne (*Medicago sativa* L.; 'LU') and birdsfoot trefoil (*Lotus corniculatus* L.; 'BT') while white clover (*Trifolium repens* L.; 'WC') was sown with each of four companion grasses: PR, hybrid ryegrass (*Lolium boucheanum* Kunth; 'HR'), meadow fescue (*Festuca pratensis* Huds; 'MF') and timothy (*Phleum pratense* L.; 'TI'). Grass and mixtures were sown in 2006 in a small-plot (1.5 × 8 m) cutting trial with 4 replications in Denmark. Plots were fertilised with 300 kg total nitrogen (N) ha^{-1} in cattle slurry, applied in four applications during the growing season of 100, 80, 60 and 60 kg N and were irrigated at drought stress. Plots were harvested five times in 2007 and four times in 2008 with a Haldrup forage harvester at a residual stubble height of 7 cm. Dry matter (DM) yield and botanical composition were determined at each harvest during two years. Results of all nine harvests have been reported previously (Elgersma and Søegaard, 2016). Following harvests of spring growth in May and second regrowth in August, hand-separated samples were analysed for each species in two replicates; for white clover and perennial ryegrass, samples were taken from the perennial ryegrass – white clover mixture. Samples were digested with a mixture of nitric acid and perchloric acid according to the AOAC procedure no. 996.16. Elements (phosphorus (P), calcium (Ca), magnesium (Mg) and potassium (K)) were determined using ICP-MS on an X-Series II instrument from Thermo Fischer (Bremen, Germany).

Due to technical problems, K contents were not measured in 2007. Effects of species, harvest date and year were analysed using the MIXED procedures of SAS, and pairwise comparisons of species are presented among legumes growing with perennial ryegrass and among grasses growing with white clover, respectively.

Results and discussion

Differences were found among legume and grass species in contents of P, Ca and Mg, but K content differed only among legume species (Table 1). Averaged across years and seasons, P contents were lower ($P < 0.001$, not shown) in the legumes functional group than in the grasses, i.e. 2.8 versus 3.7 g kg $^{-1}$, respectively. Among legume species, WC and RC had the highest P contents and LU the lowest (Table 1). Among grasses, PR had the highest P content and TI had the lowest. The mean value in TI equalled that in WC.

The Ca contents were, on average, much higher ($P < 0.001$) in legumes than in grasses, i.e. 13.3 versus 4.2 g kg $^{-1}$, respectively. Among legumes, Ca contents were highest in WC and LU and lowest in BT. Among grasses, PR and MF had higher Ca contents than HR and TI. The Mg contents were also higher in legumes ($P < 0.001$) than in grasses, i.e. 2.3 vs 1.4 g kg $^{-1}$, respectively. Red clover had the highest Mg content in the legume group and TI the lowest in the grass group. The K contents were lower in legumes ($P < 0.05$) than in grasses (19 and 23 g kg $^{-1}$, respectively). Birdsfoot trefoil had the highest K content (Table 1).

Mineral concentrations were similar in May and August in legumes except for the Mg content being higher in August whereas for Ca, the effect of harvest date varied due to species (S) × harvest (H) and H × year (Y) interactions (Table 1). In grasses, mineral contents were higher in August than in May, in particular for P and K; this effect was least found in TI (not shown). The K:(Ca+Mg) and K:Mg ratios were calculated and generally showed similar patterns between species, harvests and years. In legumes,

Table 1. Phosphorus (P), calcium (Ca), magnesium (Mg), and potassium (K) contents (g kg DM $^{-1}$) of eight species that were grown in two-species grass-legume mixtures. Data is derived from cuts in spring (May) and summer (August) in each of two harvest years.

Legumes in PR mix	P	Ca	Mg	K[1]	Grasses in WC mix	P	Ca	Mg	K[1]
RC	3.0^{a2}	13.3^{b}	2.9^{a}	19^{b}	PR	4.4^{a2}	4.9^{a}	1.4^{a}	22.5
LU	2.5^{c}	14.2^{ab}	2.2^{b}	15^{c}	TI	3.1^{c}	3.5^{b}	1.2^{b}	22.2
BT	2.8^{b}	11.1^{c}	2.0^{b}	24^{a}	MF	3.5^{b}	4.7^{a}	1.4^{a}	24.2
WC	3.1^{a}	14.7^{a}	2.1^{b}	18^{b}	HR	3.8^{b}	3.7^{b}	1.4^{a}	23.3
P-value					*P*-value				
Species (S)	< 0.001	< 0.001	< 0.01	< 0.001	S	< 0.001	< 0.001	< 0.001	NS
Harvest (H)	NS	< 0.05	< 0.001	NS	H	< 0.001	< 0.001	< 0.001	< 0.001
Year (Y)	NS	< 0.001	< 0.001	n.a[3]	Y	< 0.001	< 0.01	NS	n.a
S × H	< 0.01	< 0.001	NS	< 0.05	S × H	< 0.001	< 0.01	< 0.0001	< 0.01
S × Y	NS	NS	NS	n.a.	S × Y	NS	< 0.05	NS	n.a.
H × Y	< 0.05	< 0.001	NS	n.a	H × Y	NS	< 0.05	NS	n.a
S.E.[4]	0.09	0.55	0.09	1.4	S.E.	0.18	0.21	0.05	1.5
NRC[5]	3.5	6.2	2.2	6.0	NRC	3.5	6.2	2.2	6.0

[1] K contents were only determined in year 2.

[2] Within a column, values without a common superscript are significantly different; *P*-values are shown.

[3] n.a. = not applicable.

[4] S.E. = standard error.

[5] Dairy cow requirement (g kg DM $^{-1}$) in rations (NRC, 2001).

trends were similar to those found for their numerator, the K content, namely the highest value for BT in May (Table 1). In grasses, TI had the highest values for the ratios in May, while the K content showed S × H interactions (Table 1) namely higher values for PR, HR and MF in August than in May, but similar values for TI during both harvest dates. Contents of Ca and Mg were high in legumes but below cow requirements in grasses (Table 1).

As hypothesized, contents of minerals differed between the grasses and legumes functional groups. The concentrations of elements in plants may be affected by availability of nutrients in soil and competition between ions during uptake by plant roots. Reciprocal interactions regarding uptake exist between Mg and K or Ca. In grass tetany, the animals consume forages in which Mg concentration or bioavailability of plant Mg is low. Levels of Mg in the blood serum generally are also low. Grass tetany occurs when plants are growing rapidly in the spring at the time of heavy lactation demand by ruminants for Mg and Ca. Much attention was given to Mg in the 1970's because of the relationship between the incidence of grass tetany in livestock and low Mg in feed or high K levels in herbage which can decrease the efficiency of Mg and Ca absorption by animals (Grunes and Welch, 1989).

As hypothesized, contents of minerals also differed among species within each functional group. The results indicate a potential for optimizing dairy cow mineral intake from home-grown herbage through inclusion of legumes in the sward. For example, based on weighted averages across years, the red clover – perennial ryegrass (RC-PR) mixture contained the highest Mg and Ca contents. Among the seven mixtures, contents ranged from 2.8 (LU-PR) to 3.8 g P kg DM^{-1} (WC-PR); from 5.5 (BT-PR) to 11.6 g Ca kg DM^{-1} (RC-PR); from 1.4 (BT-PR) to 2.7 g Mg kg DM^{-1} (RC-PR); and from 15.4 (LU-PR) to 23.2 g K kg DM^{-1} (WC-MF). Values for the tetany risk indices were highest in the WC-TI mixtures and lowest in RC-PR.

Conclusions

The perennial ryegrass – red clover mixture had the most desirable Ca and Mg profile for dairy cows; moreover, this mixture was superior in terms of productivity, legume content, N content and N yield (Elgersma and Søegaard, 2016).

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Effects of coated *Lolium perenne* L. seeds on DM yield and forage quality following reseeding grassland in autumn and spring

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Abstract

Grassland improvement by reseeding is not always successful. The reasons for this include unsuitable dates of seeding, too much competition from the existing grassland sward and a lack of water. Seed coating is a way to enhance seed performance and to increase the seeding success under difficult conditions. For grassland, coated seeds (Freudenberger©) are widely used in south Germany. In a field experiment with four seeding periods (spring and autumn in 2009 and 2010), seven different seed mixtures were sown at two seeding rates (10 and 25 kg ha^{-1}). Mixtures with coated seeds were compared with others with uncoated *Lolium perenne* L. and mixtures with uncoated high sugar grass. The experiment was carried out from the date of reseeding until 2014. Reseeding generally resulted in higher percentages of *Lolium perenne* L., especially in treatments where seeds with high sugar grasses were used. Coated seed had no additional positive effects. Spring seeding was more successful than autumn seeding. Effects on DM yield, crude protein and net energy were generally small.

Keywords: coated seed, reseeding, high sugar grass, grassland renovation

Introduction

To date, the facilitative effects of grass seed coatings have not been proven. It is suggested that seeding success under unfavourable conditions can be enhanced by surrounding the grain with a coating of substances including nutrients and germination stimulants to protect the seed (Freudenberger, 2018). For example, the coating can store water and prevent dehydration of the seedling (Gorim and Asch, 2017). Furthermore, it is assumed that coating increases the seed-soil contact (Tamegger, 2008). The company Feldsaaten Freudenberger patented a coating for grassland seeds. With the coated seeds, the effects of unfavourable conditions for grasses at grassland seeding could be reduced (Elsaesser, 2011). Using the same seeding rate, the higher grain weight of coated seeds reduces the number of sown seeds but should provide better growth rate of reseeded species. This study aimed to investigate whether there are indeed facilitative effects of grass seed coatings.

Material and methods

The experimental site was located in Aulendorf (560 m asl; 900 mm average rainfall; mean temperature of 8.4 °C). Soil type was a luvisol with pH value of 6.0. The experiment was set out in four experimental blocks in a former grass field after ploughing in autumn where the basic mixture was seeded in May 2009 (Table 1). The experiment was carried out from sowing until the end of 2014 with five cuts per year and blocks differing in the date of reseeding: Experiment A: seeding date (07 May 2005); Exp. B: reseeding (16 September 2009); Exp. C: reseeding (28 May 2010); Exp. D: reseeding (08 September 2010). Reseeding was undertaken with a slot seeder. In each experimental block, seven treatments with different seed mixtures were applied with varying seeding rates in three replications (Table 1). In two treatments *L. perenne* L. seeds were coated (Coated seed©) by Freudenberger. All treatments were randomised within experimental block and fertilised with 240 kg nitrogen (N) ha^{-1}; 100 kg P_2O_5 ha^{-1}; 360 kg K_2O ha^{-1} per year.

Table 1. Treatments and seeded mixtures.

Treatments	Seed rate kg ha^{-1}	Mixture
1 basic mixture GSWT without *Lolium perenne* L.	12	25% *Fest. prat.*, 26% *Phl. prat.*, 17% *Poa prat.*, 9% *Fest. rub.*, 9% *Dact.glom*, 13% *Trif. rep.*
2 reseeding with NSI	10	NSI (= advised reseeding mixture for intensive use)
3 reseeding with NSI	25	= 88% *Lol.per.*; 12% *Trif.rep.*
4 NSI with coated seeds	10	88% *Lol.per. coated seed.*; 12% *Trif.rep.*
5 NSI with coated seeds	25	
6 NSI high sugar grasses	10	50% NSI +50% of *Lol.per.* as var. Aberavon
7 NSI high sugar grasses	25	

Prior to each harvest, the percentage of grasses and legumes were estimated according to the method of Klapp (1965). Dry matter (DM) yield was determined by weighing the whole plot (plot size 10 m^2). Net energy was determined with the Hohenheimer Futterwerttest and crude protein using Kjeldahl (VDLUFA, 1976). Analyses of variances were performed within experimental block in order to test the significant effects of treatments using the statistical program SAS. The level of significance was set to $P = 0.05$ for all tests.

Results and discussion

Percentage of *L. perenne* (%) increased during the experimental period (Table 2). Higher seeding rates led to higher percentages of *L. perenne*. There was no beneficial effect of seed coating on *L. perenne* establishment in 2012 or 2014. Thus, the suggested beneficial effects of seed coating on reseeding were not shown in this experiment. In some years, depending on seeding date, *L. perenne* sward content was significantly higher in the treatments with high sugar grasses (Table 2). The influence of the seeding period on DM yield was very low.

Coating of *L. perenne* seed did not increase DM yield or forage quality compared to uncoated *L. perenne* seeds (Table 3). In general, differences in quality parameters between treatments were small. The energy contents in all experiments were generally low and they did not meet the target of good silage quality (greater than 6.0 MJ NEL kg DM^{-1}). This was even not possible with the use of high sugar grasses and is the opposite to Jaenicke (2007). Nevertheless, DM yields were greater than expected for five cut silage protocol in Germany.

Table 2. Mean values of *Lolium perenne* L. (%) in first growths of 2012 and 2014.[1]

Seed date	Spring 2009		Autumn 2009		Spring 2010		Autumn 2010	
Treatment	2012	2014	2012	2014	2012	2014	2012	2014
1	1.0^{c}	3.3^{d}	1.7^{c}	1.7^{b}	2.7^{c}	1.7^{c}	1.7^{c}	4.0^{d}
2	9.7^{b}	13.3^{c}	4.7^{abc}	10.0^{bc}	5.7^{bc}	10.7^{b}	5.0^{ab}	9.3^{c}
3	13.3^{ab}	21.7^{ab}	7.0^{ab}	14.0^{b}	6.3^{bc}	15.3^{b}	6.0^{a}	14.7^{b}
4	10.0^{b}	18.0^{bc}	4.0^{bc}	7.7^{c}	6.0^{bc}	12.3^{b}	4.3^{ab}	18.3^{ab}
5	12.7^{ab}	18.7^{abc}	6.7^{ab}	12.7^{b}	7.0^{ab}	13.0^{b}	5.0^{ab}	17.3^{b}
6	12.0^{ab}	21.3^{ab}	6.3^{ab}	19.3^{a}	6.0^{bc}	16.3^{ab}	3.0^{bc}	22.3^{a}
7	18.3^{a}	24.3^{a}	8.7^{a}	22.0^{a}	10.7^{a}	23.3^{a}	5.7^{a}	22.7^{a}
LSD 5%	7.4	6.0	4.1	4.2	4.1	7.3	2.6	5.0

[1] Within columns, treatment values with differing lower case superscript differ significantly.

Table 3. Mean yields of DM, crude protein (Mg ha^{-1}), net energy (MJ NEL ha^{-1}) and protein (g kg^{-1}) and net energy contents (MJ NEL kg DM^{-1}) (2010-2014) for the four experiments.

Treatment	**DM**	**Crude protein**		**Net energy (MJ NEL)**	
	t ha^{-1}	**g kg^{-1}**	**t ha^{-1}**	**kg DM^{-1}**	**ha^{-1}**
Experiment A: seed date spring 2009					
1 GSWT (12 kg ha^{-1})	14.8^{a}	143	2.11^{a}	5.72	84,439^{ab}
2 NSI 10 kg ha^{-1}	14.3^{ab}	145	2.08^{ab}	5.79	82,794^{ab}
3 NSI 25 kg ha^{-1}	14.3^{ab}	143	2.05^{ab}	5.82	83,268^{ab}
4 MS NSI 10 kg ha^{-1}	13.9^{b}	142	1.98^{b}	5.78	80,425^{b}
5 MS NSI 25 kg ha^{-1}	14.8^{a}	143	2.12^{a}	5.76	85,082^{a}
6 NSI (50%) + HZG (50%) 10 kg ha^{-1}	14.1^{ab}	145	2.05^{ab}	5.82	82,188^{ab}
7 NSI (50%) + HZG (50%) 25 kg ha^{-1}	14.1^{ab}	143	2.01^{ab}	5.90	82,971^{ab}
LSD 5%	0.8		0.11		4,513
Experiment B: seed date autumn 2009					
1 GSWT (12 kg ha^{-1})	15.6	139	2.16	5.79	90,156
2 NSI 10 kg ha^{-1}	15.4	137	2.11	5.68	87,550
3 NSI 25 kg ha^{-1}	15.4	139	2.14	5.70	87,776
4 MS NSI 10 kg ha^{-1}	15.7	136	2.13	5.72	89,976
5 MS NSI 25 kg/ha kg ha^{-1}	15.7	137	2.15	5.64	88,601
6 NSI (50%) + HZG (50%) 10 kg ha^{-1}	15.6	138	2.15	5.72	89,046
7 NSI (50%) + HZG (50%) 25 kg ha^{-1}	15.5	136	2.09	5.75	88,239
LSD 5%	0.69		0.11		4,027
Experiment C: seed date spring 2010					
1 GSWT (12 kg ha^{-1})	13.7^{a}	139	1.91^{a}	5.64	77,312^{a}
2 NSI 10 kg ha^{-1}	12.7^{b}	137	1.73^{d}	5.66	71,744^{b}
3 NSI 25 kg ha^{-1}	13.4^{a}	130	1.83^{abc}	5.66	75,812^{a}
4 MS NSI 10 kg ha^{-1}	12.8^{b}	137	1.74^{cd}	5.65	71,999^{b}
5 MS NSI 25 kg ha^{-1}	13.3^{a}	137	1.83^{abc}	5.69	75,735^{a}
6 NSI (50%) + HZG (50%) 10 kg ha^{-1}	13.4^{a}	137	1.84^{ab}	5.61	75,368^{a}
7 NSI (50%) + HZG (50%) 25 kg ha^{-1}	13.4^{a}	136	1.81^{bcd}	5.68	75,850^{a}
LSD 5%	0.55		0.1		3,333
Experiment D: seed date autumn 2010*					
1 GSWT (12 kg ha^{-1})	12.8	133	1.70	5.71	73,271
2 NSI 10 kg ha^{-1}	12.8	140	1.79	5.76	73,787
3 NSI 25 kg ha^{-1}	12.6	135	1.70	5.68	71,396
4 MS NSI 10 kg ha^{-1}	12.7	136	1.73	5.71	72,687
5 MS NSI 25 kg ha^{-1}	12.5	136	1.70	5.64	70,664
6 NSI (50%) + HZG (50%) 10 kg ha^{-1}	12.2	133	1.62	5.76	70,012
7 NSI (50%) + HZG (50%) 25 kg ha^{-1}	12.3	139	1.72	5.78	71,146
LSD 5%	0.85		0.14		487

* average 2011-2014 because of late reseeding date in autumn 2010; GSWT = basic seed mixture Grassland – cutting-grazing for dry areas; NSI = mixture for reseeding of intensive used grasslands; MS = coated seed; HZG = high sugar grass. Within columns, treatment values with differing lower case superscript differ significantly.

Conclusions

Seed coating did not influence *L. perenne* development or production. The seed dates in spring resulted in higher percentages of *L. perenne* than seeding in autumn. Higher seeding rates also led to higher percentage of *L. perenne*. The use of high sugar grasses had positive effects on the development of *L. perenne.*

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Suitability of soft leafed Tall fescue (*Festuca arundinacea)* in mixtures under grazing and cutting

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Abstract

Due to its greater rooting system tall fescue (*Festuca arundinacea*) has the ability to take up water from greater depths than other grasses. Tall fescue may be more suitable for cultivation in areas with temporarily dry conditions. Until now, tall fescue has a low contribution in seed mixtures in Germany, as cattle do not accept it in pasture because of its hard blade. There are new varieties of *F. arundinacea* with softer leafs, that might be better accepted by grazers. The yield potential is higher if tall fescue are included in reseeding mixtures. Eighteen variants of single species and commercial mixtures were tested in south Germany from 2012 - 2015 in two different experiments under cutting and grazing. Under grazing, the soft leafed variety of tall fescue had only a slightly better intake than the hard leafed tall fescue or cocksfoot (*Dactylis glomerata*). While mixtures with tall fescue reached high yields, however, the maximum yield and energy contents were observed in high productive mixtures of *Lolium perenne* and *Trifolium repens*.

Keywords: *Festuca arundinacea*, tall fescue, grazing, cutting, pasture mixtures, DM yield

Introduction

Tall fescue (*Festuca arundinacea*) has the ability to retrieve water from greater depths than other grasses (Loges *et al.*, 2009). Tall fescue may be more suitable to cultivation in areas with temporarily dry conditions. Currently, tall fescue makes a small contribution to seed mixtures in Germany, as grazing cattle do not accept it because of its hard blade. Nevertheless, Schubiger *et al.* (1997) reported higher digestibility for tall fescue compared with cocksfoot, which is usually grown under dry conditions. In Swiss experiments (Mosimann *et al.*, 2010), new breeds of soft leafed tall fescue had a good suitability for grazing and even the yield potential was high in mixtures. In the present experiment, 18 mixtures and pure stands were compared under cutting and grazing conditions. The objective was to investigate if the expected high yield potential of tall fescue could be realised under cutting as well as under grazing conditions.

Material and methods

The experiment was carried out from 2012 - 2015 in Aulendorf (south Germany) on two different, but in close proximity, fields (site conditions: sandy loam; 900 mm mean rainfall, 670 m a.s.l.; mean temperature 8.4 °C). The grazing experiment was carried out in a rotational system with four paddocks and five - six grazings per year. The experimental paddock (0.18 ha) had 18 treatments of commercial grass mixtures or pure stands in four fully randomised replications (parcel size 2.7 × 8.6 m) (Table 1). The paddock was grazed with ten heifers for the duration of three - five days and then rested until next grazing (Elsaesser *et al.,* 2014). At least two times per year the paddock was mulched and fertilised with 140 kg N ha^{-1} $year^{-1}$. The swards were observed before and after grazing: before grazing the stage of plant growth was determined and the grass height and DM yield (50 × 50cm harvest area) were measured. After grazing, the residues were measured (in each plot 3 × 0.25cm^2 harvest area), grazing residues were estimated according to a scoring system where 1 = totally grazed and 10 = very high abundance of residues. These values are presented in the study here (Figure 1).

Table 1. Commercial mixtures and grass species.

No		Incl. *Tall fescue*	No		Incl. *Tall fescue*
1	Advisory mixture for pastures (intensive use GSWI)	-	10	GreenStar intensive (Barenbrug)	-
2	Advisory mixture for pastures (dry conditions GSWT)	-	11	LandGreenW963 pasture	-
3	Revital 301	-	12	*Lolium perenne* early	-
4	Progreen Pasture without clover	-	13	*Lolium perenne* late	-
5	BellMix 1200 DBF	-	14	*Lolium perenne* mixture with white clover	-
6	Country 2006 Pasture with clover (DSV)	-	15	*Dactylis glomerata* early	-
7	Country 2012 mowing pasture (DSV)		16	*Dactylis glomerata* late	-
8	Graze Max (Barenbrug)	yes	17	*Festuca arundinacea*	yes
9	GreenStarStructure (Barenbrug)	-	18	*Festuca arundinacea*, soft leaves	yes

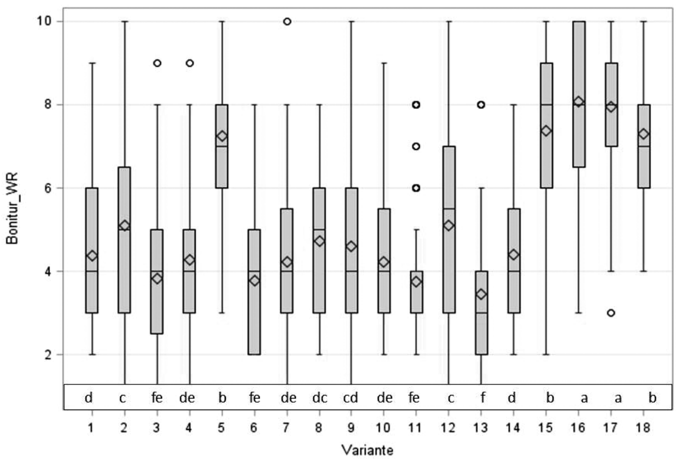

Figure 1. Scoring points for grazing residues after each grazing period (average of 2012-2015) (different letters symbolise statistical differences for $P = 0.05$).

The cutting experiment (five cuts per year; 240 kg N ha^{-1} $year^{-1}$) was carried out at a site, 500 m from the grazing experiment and had the same variants of mixtures and pure stands in a full randomised block design of small plots (2.7 × 8.6 m) with four replications. Plant samples of each variant were taken to determine dry matter (DM) yield (t ha^{-1}). The dried samples were analysed for net energy contents (MJ NEL ha^{-1}) using NIR Spectroscopy-method. Results were statistically analysed with SAS in an ANOVA procedure.

Results and discussion

Observations after grazing show (Figure 1) that the heifers dislike the treatments with cocksfoot as well as the pure stands of tall fescue regardless of whether they were soft leafed or not. Treatments with best forage intake were the commercial mixtures 3, 4, 6, 11 and the late variety of perennial ryegrass, treatment 13 ($P = 0.05$).

Under cutting conditions highest DM yields were correlated with lower energy contents. Pure stands of *L. perenne* had highest DM yields (treatment 12 and 13) (Figure 2). Mixture and pure stands of tall fescue were low in both DM yields and net energy contents. The recommended mixtures of the advisory services (treatment 1 and 2) had high DM yields and reasonable energy contents.

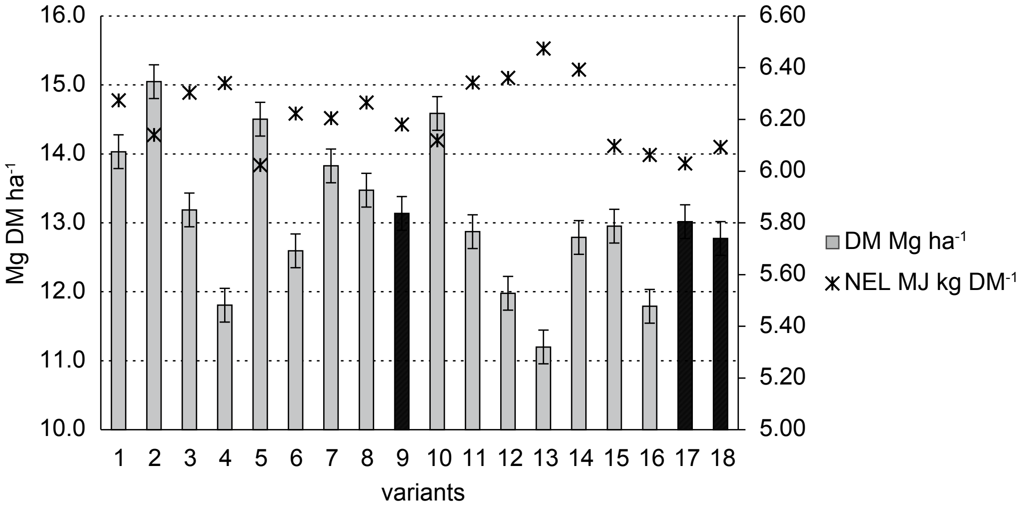

Figure 2. Dry matter yields (Mg ha^{-1}) and average energy contents (MJ NEL kg DM^{-1}) of treatments in the cutting experiment (average of all cuts in 2012-2015) (bright bars are mixtures or pure stands with tall fescue).

Conclusions

If the cattle could choose its forage, it would not select either tall fescue nor cocksfoot. The advantages of such forage could be found mainly under cutting conditions. If forage is offered to grazing cattle, the possibilities for forage selection should be restricted. Soft leafed tall fescue itself has only slightly better intake characteristics than hard leafed fescue. Best forage intakes were found for monocultures of *Lolium perenne* (treatment 13) or mixtures especially designed for grazing with high amounts of *Lolium perenne* and *White clover* (3, 6 and 11). These mixtures are correlated with lower DM yields but high energy contents. In future, if drier conditions exist and fields can not be mown because of unfavourable site conditions, grazing systems should be adapted which may restrict selection possibilities of grazing animals.

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Effect of season and species on the nutritive value of leaves of high stem trees

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Abstract

In order to investigate their potential contribution to ruminant diets, the nutritive value of the leaves of five tree species was evaluated across the seasons. The sampling campaign was conducted on a French network of agroforestry paddocks implemented 25 years ago located in the north, the centre and the south of France. Tree leaves were collected on ash (*Fraxinus excelsior*), service tree (*Sorbus domestica*), sycamore tree (*Acer pseudoplatanus*), walnut (*Juglans* × *regia* × *nigra*) and wild cherry (*Prunus avium*). The nutritive value of the collected leaves was evaluated in June, August and October 2016 by analysing their protein and fibre contents and *in vitro* digestibility. Tree leaves composition exhibited large variations between species and between seasons. From spring to autumn, average DM varied from 288 to 450 g kg^{-1}, fibre content from 383 to 338 g kg^{-1}m and crude protein content from 160 to 110 g kg^{-1}. On the contrary, *in vitro* digestibility remained quite constant across the seasons (from 67.7 to 66.9%). This result contrasts with what is observed on grasses and herbaceous legumes in which *in vitro* digestibility decreases in autumn.

Keywords: feeding value, fodder tree, species, season, leaves, agroforestry

Introduction

Summer grazing is often limited by the low production and quality of grasslands in regions with summer droughts i.e. currently the Mediterranean area but also in future European oceanic regions due to climate change. Leaves from hedgerows, coppices, shrubs or pollarded trees may become a forage resource for livestock during periods of low grasslands production (summer and autumn), either directly by browsing or fed after cutting (Papanastasis *et al.*, 2008). In order to investigate their potential contribution to ruminant diets, the nutritive value of the leaves of five tree species was evaluated across the seasons, from June to October.

Materials and methods

The sampling campaign was conducted on a French experimental network of agroforestry paddocks implemented 25 years ago. Tree leaves were collected on high stem trees from eight sheep or dairy cattle farms located in the north, the centre and the south of France. The five tree species were ash (*Fraxinus excelsior*) collected at five locations, service tree (*Sorbus domestica*) collected at two locations, sycamore tree (*Acer pseudoplatanus*) collected at six locations, walnut (*Juglans* × *regia* × *nigra*) collected at two locations and wild cherry (*Prunus avium*) collected at three locations. At each location, two samples per species were collected on different trees. Leaves (blade and petiole) were collected on the trees in late June, mid - August and mid-October) 2016. Samples were oven dried at 60 °C during 72 h and grounded to 1 mm. They were analysed for nitrogen (N, Dumas method with a Flash 2000 CHNS / O Analysers from Thermofisher on samples ground again with a vibro-broyeur from Retsch), crude protein content (CP, calculated as N × 6.25), fibre content (neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL), Goering and van Soest method, 1970), *in vitro* dry matter digestibility (IVDMD) with the enzymatic method of Aufrère (1982) adapted with the DAISY Incubator from ANKOM, and ash (550 °C during 3 h in a muffle furnace). Data were analysed using the packages GrapheR and Rcmdr (R core team, 2017).

Results and discussion

The effects of species and seasons on the chemical composition parameters of tree leaves were highly significant (P < 0.0001) and largely more important than the Species × Seasons interaction. The comparison of species means is detailed in Table 1 and of season means in Figure 1. As ADF and ADL contents showed the same pattern of significance as the NDF contents, they were not presented in this paper. Dry matter content ranged from 232 g kg^{-1} in walnut collected in June to 592 g kg^{-1} in service tree collected in October. It was significantly higher for service tree than for other species and it rapidly increased from June to August for all species. Neutral detergent fibre concentrations varied from less than 300 g kg^{-1} in walnut in October to 410 g kg^{-1} in wild cherry in June and they were significantly higher for sycamore tree than for walnut. They decreased from June to October. Crude protein concentrations varied from 72 g kg^{-1} for service tree leaves collected in October to more than 200 g kg^{-1} for walnut in June. Crude protein concentrations strongly decreased across the seasons from 160 in June to 110 g kg^{-1} in October, service tree having the lowest CP content (91 g kg^{-1}). Digestibility (IVDMD) ranged from 60.3% for field maple leaves in October to more than 75.6% for walnut in June. We did not notice any effect of the season on IVDMD.

Our previous study (Emile *et al.,* 2017) and other studies also indicated that the chemical composition and IVDMD of tree leaves varied according to the tree species (Papanastasis *et al,.* 2008, Luske and Van Eekeren, 2015). An effect of the season on DM, NDF and CP was also highlighted by Smith *et al.* (2012) for willow, but they also noticed a season effect for IVDMD. This contrast with the present study could come from the fact that in Smith *et al.* (2012) the samples included leaves and little stems.

Table 1. Average chemical composition (DM, NDF and CP, g kg^{-1} DM) and digestibility (IVDMD, %), with standard error of mean (SEM) in brackets, of tree leaves collected in 2016.

		n	DM	NDF	CP	IVDMD
Ash	*Fraxinus excelsior*	30	351 (12)^{b}	360 (8)^{bc}	148 (5)^{b}	69.9 (0.8)^{b}
Service tree	*Sorbus domestica*	12	488 (29)^{a}	343 (7)^{ab}	91 (5)^{a}	62.5 (1.1)^{a}
Sycamore tree	*Acer pseudoplatanus*	36	381 (14)^{b}	388 (6)^{c}	133 (5)^{b}	63.9 (0.9)^{a}
Walnut	*Juglans × regia × nigra*	12	342 (25)^{b}	312 (8)^{a}	156 (12)^{b}	72.8 (1.5)^{b}
Wild cherry	*Prunus avium*	18	404 (20)^{b}	372 (16)^{ab}	126 (7)^{b}	67.8 (2.1)^{ab}
Mean			383	364	134	67.1

[1] Values with the same superscript letter in the same column do not differ significantly (Tukey test, P < 0.05).

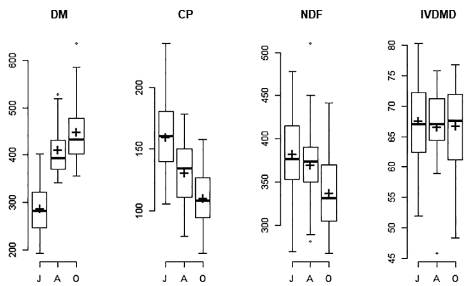

Figure 1. Effect of season (J=June; A=August; O=October) on chemical composition (DM, NDF and CP concentrations, g kg^{-1} DM) and digestibility (IVDMD, %) of tree leaves collected in 2016.

Conclusions

The chemical composition and digestibility of leaves of more than 20 years old high stem trees cultivated for timber production in agroforestry farms, exhibit large variation among tree species. Among the five studied species, walnut and ash presented the major interest for feeding ruminants. Although DM, fibre and protein contents of the leaves strongly depended on the season, the results show that the digestibility was constant from June to October, allowing the feeding of ruminants even during the seasons where grasslands are of lower productivity and quality. Further investigations have to be conducted to describe the effects of tannins and minerals on animal performances and health and to define the best practices for providing these alternative resources to ruminants.

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Pasture production estimated with the Yield-SAFE model in silvopastoral systems established with different *Pinus radiata* D. Don densities

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Abstract

In the silvopastoral systems one of the main factors affecting pasture production is tree density. Therefore, it would be very useful to have management tools to estimate long-term pasture production when silvopastoral systems are established. In this context, the Yield-SAFE is a biophysical model to predict long-term pasture production taking into account light and water availability, different management alternatives in exclusively agricultural and forest systems and also in agroforestry systems. The aim of this study was to use the Yield-SAFE model to estimate the pasture production in silvopastoral systems established in Galicia (northwest Spain) with different *Pinus radiata* D. Don densities (100 and 200 trees ha^{-1}). The results of this study showed that in the silvopastoral systems the initial tree density could be higher than 100 trees ha^{-1} because the low height of the trees does not negatively affect pasture production. At the time of tree cutting, the maximum tree density could be less than 100 mature trees ha^{-1} to guarantee pasture production. The Yield-SAFE model can be used as a management tool to find the adequate tree density that optimises the land use productivity under an agroforestry context.

Keywords: agroforestry, modelling, afforestation, light, water

Introduction

In the silvopastoral systems, pasture production generally decreases when the tree density is too high, with this effect being greater under conifer species compared with deciduous species which are characterised by slower growth and smaller stems than conifer species (Rigueiro-Rodríguez *et al.*, 2012). Yield-SAFE is a biophysical model that allows the prediction of long-term pasture production in agroforestry systems taking into account light and water availability and different management alternatives such as the tree density (van der Werf *et al.*, 2007). Therefore, when a silvopastoral system is being established, this model could be used by the farmers as a tool to decide which is the most appropriate tree species and density in each area depending on factors such as the climate or soil type. The aim of this study was to estimate the pasture production in silvopastoral systems established in Galicia (northwest Spain) with different *Pinus radiata* D. Don densities (100 and 200 trees ha^{-1}) using the Yield-SAFE model.

Materials and methods

The Yield-SAFE model, a process-based modeling concept for agroforestry systems (van der Werf *et al.*, 2007), was previously calibrated for *Pinus radiata* D. Don and a *Dactylis glomerata* L. pasture with real data from Galicia (Ferreiro-Domínguez *et al.*, 2014a). The Yield-SAFE model was used to determine the production of hypothetical silvopastoral systems in which the pasture composed of *Dactylis glomerata* L. was combined with *Pinus radiata* D. Don established at 100 trees ha^{-1} to keep the land eligible for Common Agricultural Policy (CAP) support or 200 trees ha^{-1}. In this experiment, it was simulated that the pasture was harvested three times in the spring and one time in autumn during the first ten years and then only one time in the spring and one time in the autumn because the pasture production decreases over time due to the shade generated by the trees. For the simulations we used artificial climate data retrieved from the CliPick tool (Palma, 2017) for Lugo (Galicia, northwest Spain). The simulations were carried out over 30 years. A Microsoft Excel© implementation of the model was used to provide a graphic interpretation of the results.

Results and discussion

Figure 1 shows that in both tree densities the pasture production simulated by the Yield-SAFE model (100 trees ha^{-1}; 1.76 to 3.33 t DM ha^{-1} and 200 trees ha^{-1}; 1.18 to 3.33 t DM ha^{-1}) was within the ranges of 0.11 to 5.48 t DM ha^{-1} suggested by Rigueiro-Rodríguez *et al.* (2012) and 1.57 to 7.72 t DM ha^{-1} reported by Ferreiro-Domínguez *et al.* (2014b), both in silvopastoral systems established in the same area with the same forest species. The Yield-SAFE model estimated that during the first ten years, the pasture production was the same in both tree densities probably due to the low height of the trees. However, from the tenth year the Yield-SAFE model simulated a higher pasture production in the low tree density (100 trees ha^{-1}) than in the high tree density (200 trees ha^{-1}), and in year 30 the pasture production was 37% lower in the high tree density compared with the low tree density. These results could be explained by the higher light and water competition generated by the trees in the high tree density than in the low tree density which could have limited the pasture development. The negative effect of trees on pasture production was also simulated by the Yield-SAFE model when the passage of time was evaluated because the model considers that the pasture production decreases with the increase of the tree canopy cover. Similar results were previously observed by other authors including Rigueiro-Rodríguez *et al.* (2012a) in silvopastoral systems established in the same area with *Pinus radiata* D. Don and *Betula alba* L.

On the other hand, within the European Union (EU), Article 23 of Regulation 1305/2013 (EU, 2013) as well as the derived delegate act describes that for any arable land to be eligible for CAP 2014-2020 support, tree density should not be above 100 trees ha^{-1}. This limitation, without identifying these trees as mature trees prevents farmers from establishing agroforestry practices as farmers need to plant a higher number of trees to reach this final mature tree density and when they use a higher initial tree density they lose the Pillar I payments. Moreover, the results of this study show that in the first years after the establishment of the silvopastoral systems the tree density effect on the pasture production was very low. Therefore, as was previously recommended in policy report of the AGFORWARD project, the initial tree density in the agroforestry systems could be higher than 100 trees ha^{-1} (to be selected by member states), reaching a final maximum tree density less than 100 mature trees ha^{-1} (Mosquera-Losada *et al.*, 2017) which could increase the environmental and economic benefits to farms from silvopastoral practices. In any case, the Yield-SAFE model could be used as a management tool to find the adequate tree density that optimises the land use productivity under an agroforestry context.

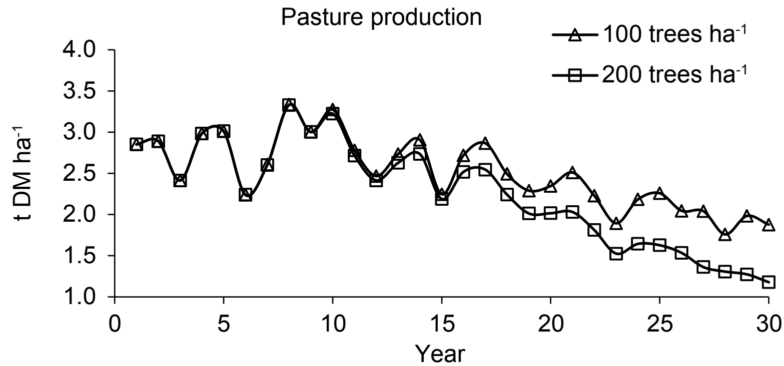

Figure 1. Pasture production (t DM ha^{-1}) estimated through the Yield-SAFE model under different tree densities (100 and 200 trees ha^{-1}).

Conclusions

In silvopastoral systems, the initial tree density could be greater than 100 trees ha^{-1} because the low height of the trees does not negatively affect pasture production. At the time of tree cutting, the maximum tree density should be less than 100 mature trees ha^{-1} to guarantee pasture production. The Yield-SAFE model can be used as a management tool to find the adequate tree density that optimises the land use productivity in an agroforestry context.

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Selenium and fertiliser application schemes in hay fields

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Abstract

The effects of selenium (Se) and fertiliser application schemes on forage Se, nitrogen (N) and sulphur (S) content and yield were studied in a western Oregon hay field. Of primary interest was whether fertilising with S and N affects plant uptake of Se applied as sodium selenate. Forage species included tall fescue (*Festuca arundinacea* Schreb.), orchardgrass (*Dactylis glomerata* L.), perennial ryegrass (*Lolium perenne* L.), white clover (*Trifolium repens* L.), and subterranean clover (*Trifolium subterraneum* L.). Treatments were assigned to 9 m^2 plots in a split plot design with three replicates; whole plots were Se and sub plots fertilisation. Selenium rates were 0, 45, and 90 g ha^{-1} and fertilisers were 0, NPK (40, 100, and 100 kg ha^{-1} of nitrogen (N), phosphorus (P) and potassium (K), respectively), and NPKS (NPK plus 30 kg S ha^{-1}). When forage regrowth exceeded 30 cm in height, plots were harvested, weighed and sampled for dry matter (DM), Se, N and S content. Fertilising increased ($P \leq 0.003$) forage yield and S content and tended to increase ($P = 0.091$) N content. Application of 0, 45, and 90 g Se ha^{-1} increased ($P < 0.001$) forage Se content from 0.10 to 2.23 and 4.33 ppm, respectively, but did not affect yield or content of N or S in forage ($P > 0.10$). Levels of Se decreased ($P < 0.001$) with time, with no fertiliser by Se interaction.

Keywords: forage, selenium, fertiliser, sulphur, nitrogen, yield

Introduction

Selenium (Se) concentration of forages grown in Oregon is lower than that required by livestock (Filley *et al*., 2007). The primary reason for this is low soil Se content. Attempts to provide supplemental Se to animals through trace minerals or injection usually fail to maintain blood Se levels necessary for optimal health and productivity. Plants require sulphur (S), but not Se, for amino acid production. However, they will incorporate some soil Se into plant selenoproteins in place of S. Several researchers have reported improved forage Se content following application of Se to pastures (Gupta and MacLeod, 1994). This practice has been studied and adopted in Oregon as a way to supplement livestock rations. Application of Se directly to pastures and hayfields increases forage Se concentration in a dose dependent manner (Filley *et al*., 2007) and improves blood Se levels (Hall *et al*., 2009), animal performance (Hall *et al*., 2013a) and immunity (Hall *et al*., 2013b). A commercially available Se product is being added to fertiliser blends but interactions remain untested. The objective of this study was to determine whether including Se in a fertiliser mix (nitrogen: N, phosphorus: P, potassium: K, and S) affects forage Se content.

Materials and methods

In the spring of 2017, a portion of an irrigated western Oregon hayfield consisting of tall fescue (*Festuca arundinacea* Schreb.), orchardgrass (*Dactylis glomerata* L.), perennial ryegrass (*Lolium perenne* L.), white clover (*Trifolium repens* L.), and subterranean clover (*Trifolium subterraneum* L.) was sampled for soil fertility and pH, and mowed to a 5 cm stubble height. Treatments were assigned to 9 m^2 plots in a split plot, crisscross design with three replicates; whole plots were Se and sub plots fertilisation. Fertiliser included 0 (none), NPK (40 kg N ha^{-1}, 100 kg P ha^{-1}, and 100 kg K ha^{-1}), and NPKS (NPK plus 34 kg S ha^{-1}) applied one day prior to Se application. Aqueous solutions of sodium selenate were applied by backpack sprayer fitted with a precision tip to deliver 0, 45, and 90 g ha^{-1} Se to the plots. Plots were harvested three times (25, 65, and 114 days post Se application). Forage grab-samples (20 per plot) to a 5 cm stubble height were collected for dry matter (DM) determination and quality (Se, N, and S content). Plots were mown to 5 cm using a cycle-bar mower and total wet weight for each plot was determined using a field scale. Urea at 50 kg N ha^{-1} was applied to fertiliser treatment plots after each harvest. Data were analysed by repeated measures ANOVA (Genstat 64-bit, Release 18.2). Factors were plot, Se, fertiliser, Se × fertiliser, time, time × Se, time × fertiliser, and time × Se × fertiliser.

Results and discussion

Results from year one are included here. Initial soil pH was 5.6, a value typical for western Oregon. Soil levels of P and K were adequate (43 and 186 ppm, respectively). Forage Se increased ($P < 0.001$) from 0.10 to 2.23 and 4.33 ppm with application of Se at 0, 45, and 90 g ha^{-1}, respectively. There was no significant fertiliser by Se interaction (P = 0.299; Figure 1). Application of Se did not affect yield, N or S content ($P > 0.10$) and no interaction was found between Se and fertiliser application. Consistent with earlier studies, overall concentration of Se decreased ($P < 0.001$) from first to second harvest, 3.73 and 0.71 ppm, respectively. Fertilising with NPK and NPKS increased overall forage yield ($P < 0.001$; Table 1). The variable response in yield with addition of S to the fertiliser may be attributed to adequate content of tissue S (mean = 0.32%) in the forage from all plots (Table 1). There was a fertiliser by harvest date interaction ($P = 0.008$) whereby the advantage of fertiliser on yield diminished by the time of the third harvest. Fertilising increased ($P = 0.003$) forage S content, with a significant ($P = 0.048$) time × fertiliser interaction (Table 1). Forage N percentage decreased ($P < 0.001$) with time of harvest (2.78, 2.29, and 2.32, respectively), but only tended ($P = 0.091$) to increase with 0, NPK, and NPKS fertilisation (2.35, 2.49, and 2.55, respectively). Future studies will include soil S and N testing to help explain these results.

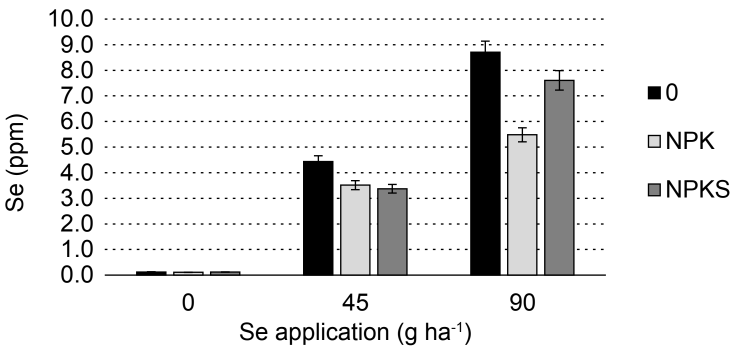

Figure 1. Effects of fertiliser and Se application on first harvest forage Se concentrations.

Table 1. Forage yield and sulphur content.

Harvest date	DM yield (kg DM ha^{-1})				Sulphur (%)			
2017	Fertiliser				Fertiliser			
	0	NPK	NPKS	ESE[c]	0	NPK	NPKS	ESE
30-May	727[a]	1,399[b]	1,299[b]		0.3037[d]	0.3833[e]	0.3978[e]	
9-Jul	1,433[a]	2,198[b]	2,345[b]	68.3	0.3068	0.3129	0.3293	0.014
14-Sep	1,559	1,736	1,522		0.2913	0.2882	0.2853	

[a,b] Values with different superscripts in the same row differ ($P < 0.05$).

[c] ESE: standard error of the means for time × fertiliser interactions.

[d,e] Values with different superscripts in the same row differ ($P < 0.05$).

Conclusions

Application of Se to hay fields and pastures increases forage Se concentration in a dose-dependent manner. Forage Se decreases from first to subsequent harvests. Fertilising with N, P, K, and S did not significantly change Se concentration in forages compared with not fertilising. Forage managers may be able to apply Se and fertiliser together if convenient. More studies on the effects of S fertilisation on yield are being conducted throughout Oregon.

Acknowledgements

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Pasture utilisation in a self-contained organic dairy grazing system in north-eastern France

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Abstract

From 2005 to 2015, an organic grazing livestock system was designed and managed to run a 35 cow dairy herd with a short calving period in late winter as a long-term experiment. The cows were rotationally grazed and had access to 22 pasture plots (34 ha) in order to maximise the amount of grazed pasture in their diet and were supplemented if necessary with hay. The pasture plots were used in different ways according to the plots' features and climatic conditions. Total pasture utilisation and grazing intake were calculated using the computerised version of the new tool 'HerbValo'. Overall, the mean annual pasture utilisation was 5.28 ± 1.38 t DM ha^{-1}, with grazing accounting for 67% of total utilisation. Spatial and temporal variability of the pasture utilisation was studied with a multivariate analysis of factors of grasslands yield. We identified nine groups that consisted of ten to 64 units coming from the set of 230 'plot-years'. These groups were different due to differences in annual pasture usage (specially grazed grass into the total production), the permanent plots features and seasonal climatic conditions during the 11 studied years. So, this global assessment allows us to summarise the experience of pasture use over this period.

Keywords: pasture-based organic dairy system, pasture utilisation, long-term experiment

Introduction

Grazing management is a challenge of knowledge and know-how for herbivore farmers, especially those seeking to increase the proportion of grazed grass in the herd diet. Many farmers (especially those engaged in organic farming) are trying to reach feed autonomy. Grazing for ruminant systems is a topical issue (Van den Pol-van Dasselaar *et al.*, 2015) and can be a good way to manage grasslands and feed livestock. It has been the subject of extensive research. This feeding system is a low cost option but demands great skills to deal with grass growth variations within and between seasons and over years. Moreover, diversity of environmental conditions is often considered as a constraint for grazing management. Therefore, rotational grazing is predominantly on small paddocks with two consequences: higher stocking densities difficult to reconcile with pasture trampling risks and a more efficient monitoring to control grass availability.

A method to describe jointly the spatial and temporal variabilities of grass production and utilisation (within a livestock grazing system) did not exist before 2017: the intake of grazing animals is only a part of the available grass used and the estimate of real pasture utilisation remains approximate. In addition, the adaptive management of pasture must consider the functions played by the different plots according to their specific features and climatic variations.

Materials and methods

An organic pasture-based dairy system was designed step-by-step and managed with no concentrate. It was located in a north-eastern French research unit in a plateau area (300 m a.s.l.) and ran from 2005 to 2015 through various climatic conditions (600 to 1,057 mm rainfall per year). This long-term experiment (Coquil *et al.*, 2014) attempted to maximise the grazing period duration (252 days on average) of a dairy herd (on average 35 cows) minimising hay supplementation. From 2005 to 2009, 36 ha and 22 plots were used (32 ha and 20 plots from 2010) through rotational grazing by January - April calving cows. Main pasture species were *Lolium perenne* L., *Festuca pratensis* L., *Dactylis glomerata* L., *Poa pratensis* L., *Agrostis sp.* and white clover (*Trifolium repens* L.) content was high from late spring. Mean stocking rate of the system was 0.87 LU ha^{-1}.

Grazing and harvesting events were registered in grazing calendars. A database including weekly grass height measurements and considerations about grass nutritive value and grazing severity was developed. These tools enabled grazing management to establish a grass budget of 30 - 35 grazing days in hand by early summer (Fiorelli *et al.*, 2002), control grass height after grazing in the 5 to 6 cm range and possibly cut refusals or decide to harvest a plot for hay instead of grazing it. These data were entered into the 'HerbValo' model (Delagarde *et al.*, 2017) to estimate the annual pasture utilisation (PU) for the different plots according to animal requirements and supplementation.

In order to describe spatial and temporal variability of PU, each plot was characterised by soil depth, upper layer soil texture, trampling sensitivity and distance from the farm buildings. Fertilisation practices, time and frequency of grazing or cutting events were taken into account according to the successive years as well as the climate conditions of the seasons. Each plot occurred 11 times (one per year, each couple plot/year defining a statistical individual called 'plot-year'). These variables were the principle variables of a multiple correspondence analysis (MCA) whilst PU and grass intake were supplementary ones. The statistical analysis was undertaken using FactomineR, an R package for multivariate analysis (Lê *et al.*, 2008). Then, an hierarchical clustering (HCA) was run to identify groups of comparable 'plot-years' (Ward, 1963).

Results and discussion

Overall, mean PU over the 11 years was 5.28 ± 1.38 t DM ha^{-1} whereas calculated mean grass intake by animals was 3.54 ± 1.58 t DM ha^{-1} (2/3 of the PU). Half of the 'plot-years' had a grass intake greater than 80% of their PU: these plots were just grazed, however, some were mechanically cut for refusals after grazing. The other plots were both grazed and cut for hay, showing the need to combine both grazing and cutting to improve overall grazing management. Total PU ranged from 2.26 to 9.07 t DM ha^{-1} $year^{-1}$ across plots and years. The lowest annual mean PU and grass intake occurred in 2015 even when the grazing duration and the number of cows were highest, however, supplementation was also very high. Conversely, the highest PU occurred in 2007, due to high rainfall during summer and a small number of cows, which allowed both trampling and hay supplementation to be limited.

Multivariate analysis and clustering provide a synthesis of the 'plot-years' diversity: nine groups of units (comprising ten to 64 'plot-years') enabled us to pool the plots with a close grazing function according to the environmental conditions of the grazing system. Figure 1 describes four group characteristics using the main variables and two supplementary variables (PU and grass intake). Cluster 1 (28 'plot-years') gathers four plots covering the 11 years of the experiment. These plots were very close to the parlour and had a deep, silty soil and were mainly grazed and mechanically cut for refusals. Their PU was higher than the median value (5.82 ± 1.38 t DM ha^{-1}). Cluster 3 (64 'plot-years') groups eight plots covering all years except 2014. These plots were often close to the parlour and had a shallower soil with a clay upper layer. They were grazed from spring to autumn and refusals were cut in early summer. Their PU was lower than the median value (4.70 ± 1.34 t DM ha^{-1}). Cluster 7 (28 'plot-years') gathers four plots covering all years except 2014. Cluster 7 plots were close to the parlour but they had a shallow soil that was sensitive to trampling. These plots were mainly cut for hay but they showed a grazing management diversity (frequency and intensity): their PU was the highest at 6.39 ± 1.04 t DM ha^{-1}. Cluster 9 (29 'plot-years') consists of six plots covering nine years (2005 and 2014 excluded). These plots were far away from the parlour, had a shallow soil and were mainly cut for hay and accordingly spread with manure: their PU was just up to the median value at 5.71 ± 0.99 t DM ha^{-1} and grass intake was low. These four clusters gather 65% of the 230 plot-years'.

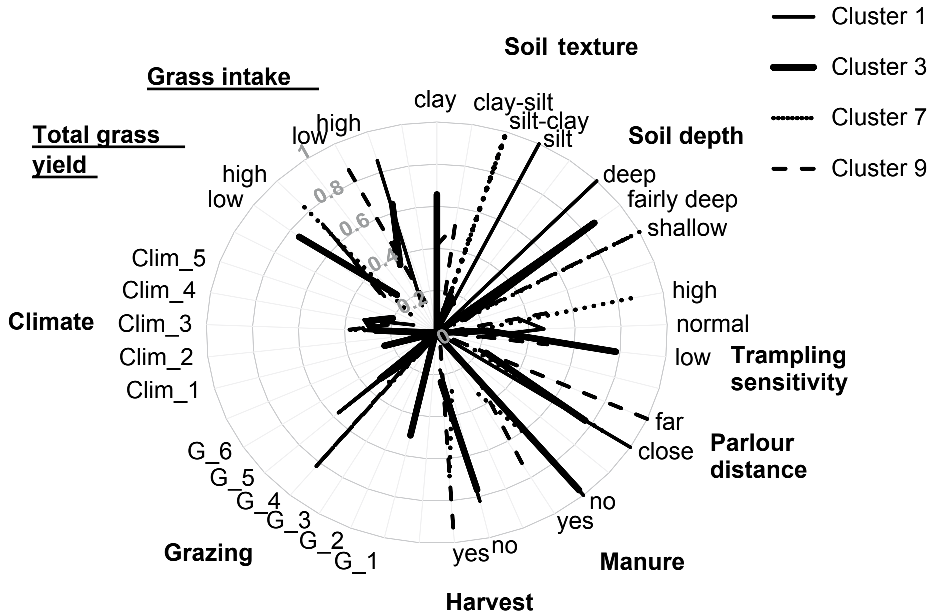

Figure 1. Features of 4 from 9 clusters (C1, C3, C7, C9) issued from multiple correspondence analysis and hierarchical clustering run on the 230 'plot-years' of the pasture grazed from 2005 to 2015. Lines indicate the frequency for the 10 variables (8 principle and 2 supplementary outlined) in the clusters 'plot-years' among modality classes. For instance, 100% of 'plot-years' in cluster 9 are shallow soils based.

Conclusion

Increased knowledge of long term pasture productive behaviour through climatic and local specific conditions should allow the farmers to develop better skills for grazing management. A challenge exists for farmers to find answers to grazing management difficulties through the assets of their environmental conditions instead of looking for inputs to overcome the constraints they are facing. A major way to preserve pasture and to ensure sustainability of agro-ecological livestock farms is to deal with variability and capitalise on experience.

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Evaluation of drought tolerance in two accessions of smilo grass (*Pipthatherum miliaceum* L.)

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Abstract

Forage production in Mediterranean environments is limited at the end of spring, when temperatures increase and insufficient rainfall becomes a limiting factor to plant growth. To assess drought tolerance of the native perennial species *Pipthatherum miliaceum* L., an experiment was carried out on two Sardinian genotypes by inducing a progressive plant water stress at the booting stage of plants. Four water stress levels were applied: no stress, mild, severe and very severe. The following parameters were measured: net photosynthesis (PN), transpiration (E), stomatal conductance (Gs), instantaneous water use efficiency (WUEi) and relative water content of leaves (RWC). Moreover, several morphological traits were compared in plants subjected to different stress levels. The results lead us to hypothesise a specific adaptation response of *Pipthatherum miliaceum* L. in terms of stomatal conductance and net photosynthesis.

Keywords: *Piptatherum miliaceum* L., persistence, genotype, drought tolerance, water stress

Introduction

Piptatherum miliaceum L. (smilo grass) is a fast-growing Mediterranean graminaceous species with high biomass production. It is considered an important component of natural pastures and its multi-functional role has been recognised in different contexts, such as mine tailings (Parraga-Aguado *et al.*, 2015), soil remediation (Arco-Lázaro *et al.*, 2017) and bioenergy (Sulas *et al.*, 2015) under rainfed Mediterranean conditions. Biomass production in the Mediterranean environment may be limited at the end of spring, when temperatures increase and insufficient rainfall becomes a limiting factor to plant growth. As a perennial grass, only plants with drought tolerance strategies associated with high water use efficiency may show adaptation to such drought conditions. An experiment was carried out with the main aim to obtain some additional information regarding the drought tolerance of *P. miliaceum*. The specific objective of the trial was to study the tolerance to water shortage of two *P. miliaceum* native populations in the final phase of the annual cycle, namely from the booting stage to plant drying, when in Mediterranean environments a water stress is more likely to occur.

Materials and methods

Two accessions of *P. miliaceum* (PM15 and PM16) differing for earliness were selected from a collection of genotypes grown in Sardinia. Accession PM16 had a heading date 20 days earlier than PM15. Twenty-two plants per accession were grown at CNR ISPAAM, Sassari, Italy. Seeds were sown in October 2013 in paper pots. Seedlings were transplanted into four litre plastic pots filled with loam soil, and placed under a plastic tunnel. Plants were kept at 100% field capacity up to the booting stage (mid-May), when progressive water stress was induced through four different levels of water shortage, each one involving a group of 12 plants. Pots were wrapped in individual transparent plastic bags to limit water loss by evaporation. Every two days starting from 15 May, each plant was weighed and transpired water was calculated as the difference with the previous weight recorded. Subsequently, water was restored in each pot after weighing, as follows: T100 (lost water was restored to field capacity); T50 (restored water to 50% of transpired water); T25 (restored water to 25% of transpired water); T0 (no water was restored). Water stress was induced until 01 July. In treatments where plants survived the drought stress, net photosynthesis (PN), stomatal conductance (Gs) and evapotranspiration (E) were measured on younger leaves on 12 June, 24 June and 01 July, using a portable infrared gas analyser (CIRAS-2, PP Systems, Hitchin, Herts., UK). Photosynthetic water-use efficiency (WUEi, instantaneous water-use efficiency) was calculated as the ratio of PN to E. At mid-June, plants subjected to severe stress T0 and T25 were dried and no ecophysiological measurements were possible on these two stress treatments. The measurement of relative water content (RWC) was carried out 20 days after the start of the water limitation. Using the formula: RWC (%) = ((Fresh weight - Dry weight) / (Turgid weight – Dry weight)) × 100. On 30 June, three plants from each treatment and accession were used to estimate the tiller height, the number of tillers and the dry weight of roots, tillers and younger leaves. For each of the three measurement dates, a one-way ANOVA (STATGRAPHICS) was performed on Gs, E, PN and WUEi, using accession and treatment as fixed factors. General linear model (GLM procedure, STATGRAPHICS) was used to test for differences between accessions and water shortage treatments for morphological traits.

Results and discussion

Stomatal conductance was always significantly higher in T100 than T50 plants (Table 1), whereas E, PN and WUEi were only significantly higher on 24 June and 01 July.

The accession PM15 had higher PN values than PM16, with significant differences appearing from 24 June. At the last relief, in well-watered plants, PM15 exhibited a WUEi value more than double that of PM16. Both accessions reacted to water shortage by decreasing leaf RWC, roughly with the same trend (average RWC = 80%). At extreme stress conditions (T0), RWC was always higher than 60%. Accession PM15 plants produced more tillers, leaves and roots, than PM16 despite water limitation. On the T50 stress treatment, PM16 showed higher and heavier tillers than PM15, but its leaves were significantly lighter. Water stress significantly affected tiller traits (height, number and weight) and dry weight of panicles, without having any significant influence on dry weight of leaves or roots. Considering the interactions (Accession × Treatment), the panicle dry weight of the combination PM15 × T100 was significantly higher than the other interactions. The late flowering PM15 accession showed a higher tolerance to water stress than the early PM16 population, thanks to well-developed root system, tillers and leaves.

Table 1. Differences induced by mild (T50) water stress on ecophysiological performances of two accessions of *Pipthatherum miliaceum* L. Different letters in each column indicate significantly different values for $P < 0.05$ (LSD test). T100 = field capacity, T50 = mild water stress, T25 = severe water stress and T0 = very severe water stress.

Accession	Treatment	Measurement date			Measurement date		
		12 June	24 June	01 July	12 June	24 June	01 July
		Stomatal conductance (Gs) (mol H_2O m^{-2} s^{-1})			Evapotraptiration (E) (mmol H_2O m^{-2} s^{-1})		
PM15	T100	109.7^{a}	124.6^{a}	79.4^{a}	4.2^{a}	4.2^{a}	2.8^{a}
PM15	T50	21.1^{bc}	3.9^{c}	-	1.3^{c}	0.9^{c}	-
PM16	T100	41.2^{b}	36.7^{b}	6.0^{b}	2.9^{b}	2.7^{b}	0.9^{b}
PM16	T50	9.1^{c}	5.4^{c}	-	0.6^{c}	0.8^{c}	-
		Net photosintesis (PN) (µmol CO_2 m^{-2} s^{-1})			Water Use Efficiency (WUEi) (µmol CO_2/mmol H_2O m^{-2} s^{-1})		
PM15	T100	7.6^{a}	7.4^{a}	6.3^{a}	1.8	1.8	2.2^{a}
PM15	T50	1.8^{c}	1.8^{c}	-	1.4	2.1	-
PM16	T100	5.2^{b}	4.4^{b}	1.1^{b}	1.8	1.7	0.9^{b}
PM16	T50	0.9^{c}	0.8^{c}	-	1.3	0.9	-

Table 2. Mean values of relative water content (RWC) and some traits of two populations of *Pipthatherum miliaceum* L., under field capacity (T100), mild (T50), severe (T25) and very severe (T0) water stress. DW = Dry Weight; ns = not significant; * significant for $P < 0.05$; ** = significant for $P < 0.005$; *** = significant for $P < 0.001$.

Accession	Treatment	RWC (%)	Tillers height (cm)	Number of tillers	Tillers DW (g)	Leaf DW (g)	Panicles DW (g)	Roots DW (g)
PM15	T100	92.8	160.0	26.3	31.6	5.6	4.6	11.1
PM15	T50	86.0	154.0	15.7	15.1	7.9	1.4	8.5
PM15	T25	78.5	154.3	11.0	19.8	6.6	1.4	7.3
PM15	T0	66.1	116.0	12.33	11.5	6.6	0.8	7.6
PM16	T100	91.4	161.7	15.3	29.9	3.7	0.8	8.3
PM16	T50	84.1	155.3	13.7	18.8	4.5	1.1	7.5
PM16	T25	79.0	136.0	12.7	14.0	4.2	0.2	5.8
PM16	T0	62.1	110.7	13.0	11.4	4.1	0.1	4.7
ANOVA								
Accession		ns	*	ns	ns	**	***	*
Treatment		***	***	*	**	ns	***	ns
Accession × Treatment		ns	ns	ns	ns	ns	***	ns

Conclusion

The results lead us to hypothesise that a drought avoidance mechanism linked to the earliness of *P. miliaceum* genotypes could be developed through a specific adaptation response in terms of Gs and PN, linked with some morphological traits, such as tiller height and dry weight of leaves and roots.

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Predicting *in vivo* digestibility of perennial ryegrass using the neutral detergent cellulase method: updating the equation

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Abstract

The objective of this study was to revaluate the neutral detergent cellulase (NDC) method to predict *in vivo* organic matter digestibility (OMD). A dataset comprising of 87 perennial ryegrass (*Lolium perenne* L.) samples were generated from five studies measuring *in vivo* digestibility using sheep. *In vivo* OMD data ranged from 640 g kg^{-1} to 880 g kg^{-1}. All sheep were offered fresh perennial ryegrass for *ad libitum* consumption. Grass samples were freeze dried at -55 °C for 72 h. After freeze drying, grass samples were milled through a 1 mm screen. All samples were analysed in triplicate for NDC to determine organic matter solubility (OMS), using the procedure outlined by Morgan *et al.* (1989). The NDC OMS results were regressed against *in vivo* OMD. The derived equation was: *in vivo* OMD = 0.540 (NDC OMS) + 0.348. The R^2 was 0.745 (r.s.d = 0.028, $P < 0.001$) indicating a significant positive correlation between *in vivo* OMD and NDC OMS. The results from this study reaffirm the use of NDC method to accurately predict *in vivo* OMD.

Keywords: *in vivo* digestibility, *in vitro* digestibility, perennial ryegrass

Introduction

Animal output from grass-based ruminant production systems is dependent on animals consuming a large quantity of high quality forage (Shalloo *et al.*, 2007). Grass organic matter digestibility (OMD) is a measurement of grass quality and is a key determinant in estimating the energetic and nutritive value of grass. Accurate prediction of grass OMD is critical as it is used to predict animal performance achievable from grass and to formulate diets (Buxton, 1996). The total OM intake and faecal collection method using sheep or cows is the scientific standard for accurately measuring OMD but this is a laborious and expensive method (Schneider and Flatt, 1975). As a result, *in vitro* enzymatic procedures have been developed to remove the need for animals to determine OMD. A modified neutral detergent cellulase method (NDC) was developed by Morgan *et al.* (1989). Due to changes in grassland management techniques used in Ireland since 1989, there is a requirement to strengthen the prediction equations. Regular updating of *in vitro* enzymatic procedures is best practise to ensure accuracy (Aufrère *et al.*, 2007). The objective of this study was to update the NDC equations to ensure the accuracy of the method in predicting *in vivo* OMD.

Materials and methods

A dataset comprising of 87 perennial ryegrass (*Lolium perenne* L.) samples were generated from five studies measuring *in vivo* digestibility, using four sheep per grass treatment. Treatments applied were varied in pre-grazing herbage mass from 936 kg DM ha^{-1} to 6,230 kg DM ha^{-1}. The grasses were collected from February through to October and across three separate years. All studies were carried out at Teagasc, Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland. Data for *in vivo* OMD data ranged from 640 g kg^{-1} to 880 g kg^{-1}. All studies used a Latin square experimental design. Depending on the size of the study, differing number of periods were included in each Latin square. There were 12 days in each period; six days adaptation followed by six days measurement (measurement phase). The sheep were individually housed in stalls (1,625 × 610 mm) which were raised 740 mm above ground level, allowing for the total collection of urine and faeces. Animals had *ad libitum* access to water and a salt block at all times. Sheep were blocked according to bodyweight and from within block were randomly assigned to homogeneous groups. Bodyweight was measured each period using electronic portable weighing scales and the WinWeigh software package (Tru-test Ltd, Auckland, New Zealand). Prior to the experiments, and between periods, the sheep grazed outdoors as a group with *ad libitum* access to a predominantly perennial ryegrass sward.

During each period, grass was harvested daily at 08:30 h with a motor lawn mower (Etesia UK Ltd., Warwick, United Kingdom). The grass was offered to the sheep twice daily at 08:30 h and at 16:00 h for *ad libitum* consumption, to allow a 10% refusal rate. Approximately 50% of the grass was offered in the morning immediately after cutting and the remaining grass was refrigerated at 4 °C. During this period of refrigeration the grass was spread out to avoid anaerobic heating. The quantity of fresh grass offered was adjusted daily for DM. One grass refusal sample per animal was collected and the samples were bulked by treatment. A sample of the daily grass offered was frozen immediately at -20 °C. The frozen samples were subsequently bowl chopped and freeze-dried (LS40+chamber, MechaTech Systems Ltd., Bristol, UK) at -55 °C for 72 h. The grass samples were milled through a 1 mm screen using a Cyclotech 1093 Sample Mill (Foss, DK-3400 Hillerød, Denmark). Following milling, the grass samples were bulked per treatment per period. Faeces were naturally voided into faecal collection trays that were placed directly behind and underneath the sheep. Total faecal output from the previous 24 h was weighed and recorded during the measurement phase. Following weighing, the faeces were homogenised by mixing and a 20% representative sample per sheep was retained daily. Individual sheep daily faecal samples were weighed and frozen immediately at -20 °C. Samples were defrosted prior to drying at 60 °C for 48 h or until dry in a Binder FED 720 (Binder GmbH, Tuttlingen, Germany) drying oven. Daily faecal samples were then bulked per sheep per period. The faecal samples were milled through a 1 mm screen using a Cyclotech 1093 Sample Mill (Foss, DK-3400 Hillerød, Denmark).

The chemical composition of the offered and refused grass and faeces were analysed using similar methods. Grass samples were analysed in triplicate using the *in vitro* NDC method of Dowman and Collins (1982) as modified by Morgan *et al.* (1989) to obtain an OMS value for each grass. To establish the prediction equations, the NDC OMS results were regressed against *in vivo* OMD. Data were analysis using the REG procedure in SAS 9.3.

Results and discussion

A total of 87 perennial ryegrass samples were used to determine the relationship between *in vivo* OMD and the derived equation was: *in vivo* OMD = 0.540 (NDC OMS) + 0.348. The R^2 value achieved was 0.745 (r.s.d = 0.028, $P < 0.001$) indicating a significant positive correlation between *in vivo* OMD and NDC OMD. The new equation has a similar accuracy to the previous equation as developed by Stakelum *et al.* (1988). Due to the greater number of grasses included and the increased number at various stages

Table 1. Mean chemical composition of the 87 grass samples used in calibration of the updated neutral detergent cellulase equation.

	Mean	S.D	Max	Min
In vivo organic matter digestibility (g kg^{-1})	781	50	884	650
Dry matter intake (% body weight (kg))	2.35	0.54	4.05	1.18
Organic matter (g kg^{-1})	911	13	934	876
Neutral detergent fibre (g kg^{-1})	513	56	609	372
Acid detergent fibre (g kg^{-1})	304	71	491	202
Crude protein (g kg^{-1})	201	55	334	95
Neutral detergent cellulase organic matter solubility (g kg^{-1})	741	95	935	485

of growth, the new equation is invariably more robust. To extend the application of this information, further equations should be developed for growth stage of grass, sward species and types and seasonal effects. This would include development of separate equations for perennial ryegrass only swards and for mixed species swards.

Conclusion

In this study, the greater number of samples included has resulted in the relative standard deviation (r.s.d = 0.028) being slightly higher than the relative standard deviation achieved by (Stakelum *et al*., 1988) (r.s.d = 0.021). This equation will allow for predictions of grass quality to be made over a wider range of samples throughout the growing season, with particular improvement in application for samples at the extremities of digestibility for perennial ryegrass swards.

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Demonstrating the benefits on integrating livestock into arable rotations

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Abstract

There is a growing requirement for arable farmers to improve soil health and find alternative methods to deal with arable weeds, in light of herbicide resistance. More arable farmers are looking to grass leys, forage crops and grazing livestock to rejuvenate poorly performing fields. A number of trials are being conducted by AHDB on arable farms using a range of crops and livestock to generate evidence and demonstrate different management approaches to local arable farmers. One trial in Oxfordshire will compare a recently reseeded arable field where half the field has been sown with a perennial ryegrass and white clover ley and the other half with an herbal ley. Sheep performance and soil health metrics will be monitored and future yields of the fields tracked. Similar trials are being planned in Norfolk for sheep, and Gloucestershire for cattle. Other work investigates whether there are any benefits to grazing cover crops with sheep before drilling arable crops or planting potatoes in terms of soil health and structure. The ambition is that by providing agronomic and financial evidence to arable farmers, a wider number of opportunities will become available to livestock farmers, for example, joint ventures between dairy and arable farmers to grow protein crops.

Keywords: livestock, arable systems, soil health, beef, sheep

Introduction

Profit margins are likely to reduce on arable land due to the inability to control weeds and poor soil health, within a volatile price environment due to market uncertainty arising from Brexit (AHDB, 2017), creating a challenge for arable farmers. A possible solution is the integration of livestock in arable rotations to provide income from cover or break crops plus possible improvements to soil health. There is growing interest by the wider industry, for example, the National Sheep Association recognise it as a growth area for the sheep industry and produced a booklet to help sheep farmers build relationships with arable farmers (NSA, 2017).

Currently, limited evidence is available on the consequences of integrating livestock on soil, field, profitability of individual businesses and markets due to changes driven by introducing novel enterprises onto farms at all levels. For example, a recent review commissioned by AHDB on cover crops identified that limited research exists to show the effect of cover crop destruction by grazing on the availability of nutrients (AHDB, 2016). It is important that the evidence is gathered at field scale so it is meaningful for farmers.

Materials and methods

Sheep demonstration, Oxfordshire

A 10 ha (25 acre) field with a soil type of Cotswolds Brash, good fertility and high pH was selected to be part of this demonstration. It had previously been in arable crops and was divided into two sub-divisions, with one half sown with a grass/clover ley and the second half sown with multi-species mixtures in autumn 2016 (Table 1). Soil analyses and previous crop maps were available and were used as the baseline, with follow-up soil assessment being collected during the project.

Table 1. The mixtures used in the sheep demonstration in Oxfordshire.

Variety	Type	Grass/clover (kg $acre^{-1}$)	Multi-species (kg $acre^{-1}$)
AberMagic	Intermediate diploid	2	
AberGreen	Intermediate diploid	3	3
AberWolf	Intermediate diploid	3	3
AberAvon	Late diploid	3	
AberChoice	Late diploid	2	
Presto	Timothy	1	1
AberPasture	White clover blend	1	1.5
AberClaret	Red clover blend		1.5
Puna II	Chicory		1
Tonic	Plantain		1
	Total	15	12

Grazing rotations were established with one group of 120 ewes and twin lambs grazing the grass and clover paddocks and a second group of 120 ewes plus twin lambs grazing the multi-species section. The daily animal demand was 58 kg DM ha^{-1}.

Pasture cover readings were recorded weekly and weights of ewes and lambs were collected as they went onto the fields and the lambs were weighed at eight weeks of age and again at weaning (13 weeks of age). The aim was to capture performance of these leys, alongside fertiliser use, to provide guidance to other farmers replicating this system.

Beef demonstration, Gloucestershire

Two fields were established in grass/clover or herbal grass/clover leys in September 2017. Measurements will take place over a five year period including the year before the leys were sown (2017), the three years of livestock grazing (2018 to 2020) and the subsequent arable crop (harvest year 2021). The fields were split to ensure 10 ha of each mixture (Table 1) was sown to ensure direct comparisons. These areas will be grazed by growing beef cattle. Two additional fields were established with grass/clover mixtures for cutting only to ensure the impact of grazing versus cutting can be assessed. One more field was split with half sowed to grass/clover ley and the second half being kept in arable to evaluate the benefit of a grass ley within the rotation.

Detailed soil assessments were carried out following harvest in stubble fields before any cultivations (15 to 22 August 2017). The grass/clover and multi-species leys were established in mid-September. Soil assessments included penetration resistance (topsoil), shear strength (topsoil), soil bulk density, visual evaluation of soil structure (VESS) and visual soil assessments (VSA). Soil samples were taken and analysed for pH, phosphate, potash, magnesium, organic matter, total nitrogen, textural classification, soil microbial biomass and soil respiration.

Grazing rotations will be established with groups of growing cattle allocated to either grass/clover or multi-species leys and their liveweight gain and stocking rate monitored over three grazing seasons. Pasture cover will be recorded weekly. The aim is to capture performance of these leys, alongside fertiliser use, to provide guidance to other farmers replicating this system.

Results and discussion

These trials have only just started and no results are currently available.

Data collection from the sheep demonstration in Oxfordshire was stopped in May 2017 due to a significant reduction in pasture cover due to low growth as a result of low rainfall. The trial will be repeated in 2018 and 2019.

Animals will be introduced into the beef demonstration in Gloucestershire in spring 2018. The initial soil assessment results from the beef project have been collated (Table 2) and will be used as the baseline.

Table 2. The initial soil assessment results for beef demonstration in Gloucestershire.

	Field 1 Grass/clover	Field 1 Multi-species	Field 2 Grass/clover	Field 2 Multi-species
pH	6.9	6.9	7.3	7.1
Extractable phosphate (mg l^{-1})	8.5	10.3	9.2	8.3
Extractable potash (mg l^{-1})	99.1	76.9	191.3	178.1
Organic matter (%)	6.5	6.2	7.2	9.8
VESS score[1]	1.8	1.5	1.9	1.6
VSA score[2]	24.7	23.4	24.2	27.3
Bulk density (mid topsoil) (g cm^{-3})	1.16	1.30	1.25	1.23

[1] = visual evaluation of soil structure (1 - 5 of scale).

[2] = visual soil assessments (0 - 32 scale).

Conclusion

This activity will ensure evidence-based decisions can be made by beef, sheep and arable farmers on the expected performance of leys, livestock and subsequent arable crops.

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Effect of nitrogen application rate on dry matter production of multispecies and perennial ryegrass swards

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Abstract

A simplex-centroid design experiment was used to investigate the DM yield potential of grass, legume and herb mixtures in a frequently defoliated system. Eight pasture mixtures with differing proportions of three plant functional groups, but with a minimum of 40% grass inclusion were selected. Species included were three grasses: perennial ryegrass (PRG, *Lolium perenne* L.), timothy (*Phleum pratense* L.) and cocksfoot (*Dactylis glomerata* L.), three legumes: white clover (*Trifolium repens* L.), red clover (*T. Pratense* L.) and greater birdsfoot trefoil (*Lotus pendunculatus* L.), and three herbs: ribwort plantain (*Plantago lanceolate* L.), chicory (*Cichorium intybus* L.) and yarrow (*Achillea millefolium* L.). Four N input levels, 0, 45, 90, 135 kg N $ha^{-1}yr^{-1}$ were applied to each mixture and were compared to a PRG only control receiving 250 kg N $ha^{-1}yr^{-1}$. Plots were harvested and herbage was weighed by a Haldrup forage harvester every 21 - 30 days from April - October and a sample of herbage was taken for DM determination. Data analysis was conducted using SAS 9.4. All mixtures responded linearly to increasing N. The 60% legume sward produced 14,721 kg DM ha^{-1} at 0 kg N ha^{-1} compared to the PRG only sward receiving 250 kg N $ha^{-1}yr^{-1}$ which produced 12,106 kg DM ha^{-1} ($P < 0.001$). In conclusion, high legume containing swards produced more herbage than PRG only swards despite receiving lower N inputs.

Keywords: multispecies swards, nitrogen

Introduction

Currently in the temperate regions of the world, grasslands are dominated by monoculture grass swards with small quantities of clover (Nobilly *et al.*, 2013). Reliance on monoculture swards requiring high levels of nitrogen (N) fertiliser inputs has become less economically viable due to volatility in price and less environmentally acceptable given N use restrictions in the EU (Lüsher *et al.*, 2014). Multispecies swards can increase biomass production from lower inputs of N compared to conventionally sown monoculture perennial ryegrass (*Lolium perenne* L.) PRG swards (Kirwan *et al.*, 2007; Nyfeler *et al.*, 2009). The enhanced productivity of more botanically diverse swards has been attributed to species complementarity and facilitation i.e. where resources are used more efficiently by a greater number of species or the promotion of certain species with superior traits due to interspecific competition between plants in the sward (Loreau and Hector, 2001). A number of studies have been conducted with species from two functional groups (grasses and legumes) as this type of sward has the ability to be more N self-sufficient due to N fixation abilities and legumes can offer a higher plane of nutrition to grazing animals (Lüsher *et al.*, 2014). However, more recently, interest has grown in the inclusion of a third functional group (Sanderson, 2010). A number of forage herbs have been identified that demonstrate high productivity and feeding value potential (Sanderson, 2010), e.g. ribwort plantain (*Plantago lanceolate* L.) and chicory (*Cichorium intybus* L.). Herbs with differing growth strategies may also be complementary in terms of resource utilisation when grown with grasses and legumes and may offer potential for further improving herbage yield in swards (Jing *et al.*, 2017). The objective of this study was to quantify the DM production of a range of multispecies swards at varying N levels and to compare them to the DM production of a PRG sward receiving 250 kg N ha^{-1} yr^{-1} (PRG250).

Materials and methods

A simplex design experiment was established at UCD Lyons farm in 2013 to investigate the DM production potential of a range of multispecies swards. The experimental layout followed the simplex design as described by Kirwan *et al.* (2007) and was designed to investigate biomass production from (1) a wide range of grass, legume and herb proportions grown in mixtures and grass monocultures (2) over four different levels of N inputs. Eight pasture mixtures were selected using a constrained simplex-centroid design with different proportions of three functional groups. There was a constraint imposed i.e. there must be at least 40% grass in each mixture (no more than 60% legume or herb). The three functional groups, each with three species were grasses: perennial ryegrass (PRG*; L. perenne* L.), timothy (*Phleum pratense* L.) and cocksfoot (*Dactylis glomerata* L.), legumes: white clover (*Trifolium repens* L.), red clover (*T. pratense* L.) and greater birdsfoot trefoil (*Lotus pedunculatus* L.), and herbs: ribwort plantain, chicory and yarrow (*Achillea millefolium* L.). The eight pasture mixtures were evaluated at three levels of species richness i.e. one, two or three species per functional group. Level one of richness included one species from each functional group, level two included two species from each functional group and level three included three species from each functional group (eight mixtures × three levels of richness = 24 mixtures in total). The design was replicated at four different N fertiliser application rates (0, 45, 90 and 135 kg N ha^{-1} yr^{-1}), resulting in a total of 96 plots (24 mixtures × four N rates) and was compared to the PRG250 sward (replicated four times). Plots measured 1.95 × 10 m and were cut eight times per year in a simulated grazing routine from April to November in 2014 and 2015 to a height of 4 cm. The mean interval between harvests was 29.5 (± 5.5) days. Total herbage fresh yield was weighed by a Haldrup forage harvester (Logster, Denmark) and a sample was taken for DM determination. Fertiliser was applied using the FIONA probe (Fiona Maskinfabrik A/S, DK 5400 Bogense, Denmark) before harvest 1 and after harvests 1, 2 and 3 for the plots receiving 45, 90 and 135 kg N ha^{-1} yr^{-1}, and before harvest 1 and after each harvest thereafter for the PRG250 sward. The cumulative DM production was determined by summing the pre-cutting herbage yield at each harvest each year. Data analysis was conducted using PROC GLM in SAS 9.4, where N was a continuous variable, year was a random effect and species richness was included in the model.

Results and discussion

There was a linear increase in DM production in response to applied N (Figure 1), especially in the grass and herb dominant swards ($P < 0.001$ for grass and herb dominant versus $P < 0.01$ for legume dominant swards). Legumes interacted positively with grasses and herbs ($P < 0.001$ and $P < 0.001$, respectively) resulting in increased DM production. The 60% legume sward produced 14,721 kg DM ha^{-1} at 0 kg N ha^{-1} compared to the PRG250 sward which produced 12,106 kg DM ha^{-1} ($P < 0.001$; Figure 1). Nyfeler *et al.* (2009) showed that mixtures fertilised with 50 kg N ha^{-1} yr^{-1} produced DM yields comparable to grass monocultures fertilised with 450 kg N ha^{-1} yr^{-1} when the legume proportion was between 50 and 70% of the sward DM. These results indicate that multispecies swards may be more sustainable than PRG monocultures due to their reduced requirement for artificial N inputs. The productivity of more diverse swards has been attributed in part to complementarity and facilitation between species, where resources are used more efficiently (Jing *et al.*, 2017). In the current study, the grass species in the 60% legume sward at 0 kg N ha^{-1} utilised the N produced by the legume component of the sward to increase its production. Well balanced mixtures including legumes requiring low N inputs could reduce both environmental effects and economic cost of herbage production through reduced N usage. However, if multispecies are to be relevant in ruminant production systems, it is important that they are evaluated under grazing conditions to assess the effect of grazing on such swards.

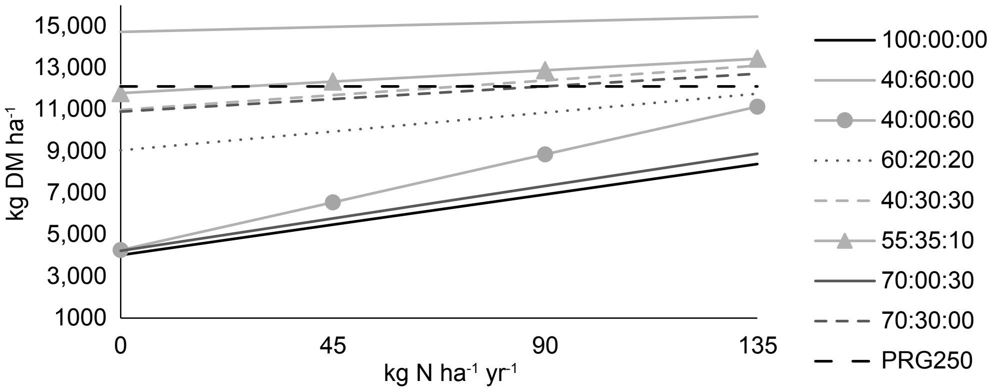

Figure 1. The effect of N application rate on the annual DM production of a range of multispecies swards, compared to a perennial ryegrass only sward receiving 250 kg N ha^{-1} yr^{-1}. Ratios relate to grass : legume : herb proportions (means are an average of the three levels of richness and of the two years).

Conclusion

Multispecies swards show potential for increased DM production from lower N inputs when legumes are included in the sward.

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Dry matter production of multispecies and perennial ryegrass swards under actual and simulated grazing

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Abstract

Productivity of multispecies swards compared to perennial ryegrass (*Lolium perenne* L.; PRG) swards under intensive grazing has not been investigated. A 5 × 2 factorial experiment was used to investigate the effect of grazing on multispecies swards over two growing seasons. Five sward types (replicated four times) were examined: 1) PRG only sward receiving 250 kg nitrogen (N) ha^{-1} yr^{-1} (PRG250), 2) PRG only sward (PRG90), 3) PRG and white clover (*Trifolium repens* L.) sward (PRGWC), 4) a six species (6S); three grasses and three legumes and 5) a nine-species sward (9S); three grasses, three legumes and three herbs. Swards 2 - 5 inclusive each received 90 kg N ha^{-1} yr^{-1}. Defoliation methods applied were simulated grazing (SG) by a harvester and actual grazing (AG) by cattle. Simulated grazed plots were cut every 21 - 30 days from April - November and a sub-sample of herbage was taken for herbage DM determination. A pre-grazing strip was cut from the AG plots for yield determination and the remainder grazed to 4 cm. Annual and seasonal yields were analysed using PROCGLM in SAS 9.4. There was no effect of defoliation method on PRG swards, however, AG reduced annual herbage DM production for the PRGWC, 6S and 9S swards compared with SG ($P < 0.001$).

Keywords: multispecies swards, actual versus simulated grazing

Introduction

Sustainable intensification entails delivering safer, nutritious food from the same land area whilst maintaining ecosystem service delivery (Smith, 2013). Reliance on monoculture swards coupled with high levels of nitrogen (N) fertiliser inputs has become less economically viable due to volatility in price and environmentally acceptable given N use restrictions in the European Union (Lüsher *et al*., 2014). Legume containing multispecies grasslands, which may require comparatively lower levels of N inputs, have shown potential for increased herbage dry matter (DM) production in plot scale studies (Lüsher *et al*., 2014). The addition of some forage herbs has also been shown to be beneficial. This may in part be due to complementary resource utilisation facilitated through adoption of differing growth strategies (Jing *et al*., 2017). Herbage DM production can be evaluated under both cutting (simulated grazing) and grazing regimes, with cutting being the more efficient method with respect to available resources within most research projects. However, sward productivity under cutting regimes tends to be higher (Jing *et al*., 2017) and more stable (Creighton *et al*., 2012) than under grazing, as simulated grazed plots (SG) are not subject to the stresses of treading, urination, pulling and selective grazing of particular species by grazing livestock (Jing *et al*., 2017). The objective of this study is to examine the effect of actual versus simulated grazing on annual and seasonal herbage DM production of multispecies swards compared to perennial ryegrass (*Lolium perenne* L.; PRG) only swards.

Materials and methods

A 5 × 2 factorial experiment was set up in UCD Lyons Farm with five sward types and two defoliation methods. The five sward types (replicated four times) were: 1) PRG only sward receiving 250 kg N^{-1} ha yr^{-1} (PRG250), 2) PRG only sward (PRG90), 3) PRG and white clover *(Trifolium repens* L.*)* sward (PRGWC), 4) six species sward (PRG, timothy (*Phleum pratense* L.), cocksfoot (*Dactylis glomerata* L.), white clover, red clover (*Trifolium pratense* L.) and greater birdsfoot trefoil (*Lotus pedunculatus* Cav). (6S) and, 5) nine species sward (9S) containing each species included in the 6S sward plus three herbs; ribwort plantain (*Plantago lanceolata* L.), chicory (*Cichorium intybus* L.) and yarrow (*Achillea millefolium* L.). Swards 2 - 5 each received 90 kg N ha^{-1} yr^{-1}. The two defoliation methods were simulated grazing (SG) and actual grazing by cattle (AG). The SG plots were 1.95 × 10 m and the AG plots were 10 × 10 m. Each defoliation method had its own arrangement of plots in the same paddock with sward types randomly assigned to each plot within a replicate block. Both defoliation methods were harvested concurrently eight times from April - November in 2015 and 2016 to simulate a grazing routine to a post grazing sward height (PGSH) of 4 cm. The interval between harvests was 29 (± 5.5) days. Total SG plot fresh yield was cut and weighed by a Haldrup forage harvester (Logster, Denmark). A 1.5 × 10 m strip from AG plots was cut and weighed by the harvester. A 250 g sample of fresh herbage was taken and dried at 45 °C for 72 hours for herbage DM determination. The remaining herbage on the plots was grazed by two cattle (*Bos Taurus* L.*)* who grazed each plot to a target PGSH of 4 cm. Fertiliser was applied using a FIONA probe (Fiona Maskinfabrik A/S, Bogense, Denmark) before harvest 1 and after harvests 1, 2 and 3 for the 90 kg N fertiliser rate (22.5 kg N ha^{-1} at each application) and before harvest 1 and after harvests 1, 2, and 3 (41 kg N ha^{-1} at each application) and after harvests 4, 5, 6 and 7 (21.5 kg N ha^{-1} at each application) for the 250 kg N rate. Annual and seasonal cumulative herbage DM production was determined by summing the appropriate pre-grazing herbage mass. The grazing season was divided up into spring (harvests 1 and 2), summer (harvests 3 - 5) and autumn (harvests 6 - 8). The data was analysed as 5 × 2 factorial using PROC GLM in SAS 9.4. The model included the effect of sward type, defoliation method, year and associated interactions with individual plot serving as the experimental unit.

Results and discussion

If multispecies swards are to be relevant in ruminant production systems, it is important that they are evaluated under grazing conditions. In the current study, there was an interaction between sward type and defoliation method on annual herbage DM production ($P < 0.01$). Both PRG swards were unaffected by defoliation method ($P > 0.05$), however, the PRGWC, 6S and 9S swards had lower herbage DM production under AG compared with SG ($P < 0.05$; Figure 1 (a)). In spring and summer, there was an interaction between sward type and defoliation method, the PRG250 sward was not affected by defoliation method, however, all other sward types had a higher level of production under SG than AG (Figure 1 (b) and (c)). In autumn, the PRG250 sward had higher herbage DM production ($P < 0.05$) than all other sward types, with the other sward types remaining undifferentiated. Overall, in autumn, the AG plots had higher herbage DM production than the SG plots (3,185 vs 2,635 respectively; SEM 107.0; $P < 0.01$). The similarity of the yields of PRG swards under AG and SG, agrees with findings by Creighton *et al.* (2012), however, the swards containing legumes in the current study had reduced annual herbage DM production under AG. In a study by Collins *et al.* (2014), the yields of PRG only swards were the same under SG and AG but similar to the current study, the yields of swards containing legumes reduced under AG. This was a result of the cattle having a preference for legume and herb species, thus reducing the persistence, causing a dominance of the grasses in the sward. Jing *et al.* (2017) also reported lower legume and herb proportions under AG compared with SG and lower DM production as a result.

Conclusion

Multispecies swards show potential for improvement in herbage DM production from lower N inputs, however, their production is reduced under intensive grazing. This suggests that if multispecies swards are to be evaluated for use in animal grazing pastures, they should be investigated under grazing conditions to accurately assess them.

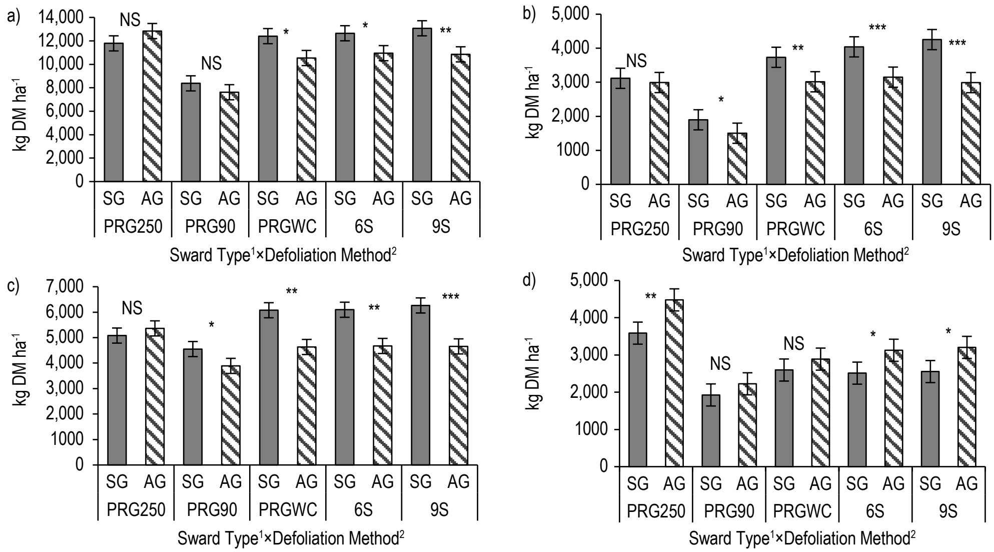

Figure 1. The effect of sward type and defoliation method on the (a) annual (b) spring (c) summer (d) autumn DM production (kg DM ha^{-1}; least square means ± SEM as error bars).
[1]PRG250: PRG only sward receiving 250 kg N ha^{-1} yr^{-1}, PRG90: PRG only sward; PRGWC: PRG and white clover sward, 6S: 6 species swards 9S: 9 species sward, all receiving 90 kg N ha^{-1} yr^{-1}, [2]SG = simulated grazed. AG = actual grazed. Ns = Non-significant. **P* < 0.05, ***P* < 0.01, ****P* < 0.0001.

Acknowledgements

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Festulolium in Ireland – seasonal yield and quality assessment

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Abstract

Festulolium grasses or hybrids between any ryegrass (*Lolium*) and fescue (*Festuca*) species offer, through rearranged genomes amongst parental species, improved resilience to climate induced stresses in reseeded grassland. Since 2012 EUCARPIA (the European Association for Research on Plant Breeding) has conducted an eight country Europe-wide coordinated network of ten field experiments using 15 Festulolium and six control varieties of the species' parents. The Irish field trial was sown in May 2013 in Athenry, Co. Galway, adjacent to the DAFM National List/Recommended List Variety trials. The trial was cut under a conservation or silage harvest protocol, with two silage cuts and three later cuts. Results show that the hybrids used have yield and quality values clustered around those of their diploid and tetraploid Italian ryegrass controls. Likewise, the hybrid types demonstrated ground cover scores similar to the ryegrass component of the parent controls.

Keywords: Festulolium, yield, quality, ground cover

Introduction

The name 'Festulolium' is derived from a combination of *Lolium*, and *Festuca*, the respective genera of ryegrass and fescue. All possible outcomes of crosses between perennial ryegrass (*L. perenne* (Lp)) or Italian ryegrass (*L. multiflorum* (Lm)), and meadow fescue (*F. pratensis* (Fp)) or tall fescue (*F. arundinacea* (Fa)) fall under the term Festulolium. Ryegrass varieties dominate reseeded grassland in Western Europe and Ireland, in particular, due to their wide adaptability, rapid establishment, very high response to high fertility (particularly added N), and their production of high yields of highly digestible forage over a long growing season. However, ryegrasses can suffer from poor persistency and ground cover, especially under climatic stress from water logging or drought, making their use significantly less cost-effective under marginal soil and climatic conditions. Fescues contribute more mid-summer growth, are deeper rooting, have better disease resistance, more drought tolerance and improved winter hardiness leading to greatly improved persistency. However, they have relatively poor palatability and digestibility, are generally less responsive to increased fertiliser and will not support intensive animal production. The objective of Festulolium breeding programmes is to capture the best traits of each species for specific climatic conditions. The intergeneric hybrids are produced by conventional breeding techniques and the choice of the appropriate parent combination depends on where the crop will be grown, and on the expected climatic stresses. While non-ryegrass species currently account for about 1% of Irish agricultural grass seed imports, they are used at low levels in all branded 'wetland' seed mixtures sown on about 10% (8,000 ha) of the area sown annually (DAFM Pers. Comm.). The requirement for alternative species is expected to continue to increase as more marginal and wet grasslands are reseeded for intensive fodder production.

Materials and methods

Until recently, agronomic assessment of *Festulolium* in the field has been limited by seed availability or restricted to particular locations or controlled environments. Since 2012, EUCARPIA has conducted a Europe-wide coordinated field experiment of 15 Festulolium varieties and six control varieties of the species parents. A network of ten trials of the same 21 genotypes was set up in eight countries: Belgium

(ILVO), Czech Republic (DLF), France (INRA), Ireland (DAFM and Teagasc), Norway (Bioforsk/Graminor), Poland (DANKO), Serbia (IKBKS) and UK (IBERS). Seed was provided by five European breeding companies: DLF, IBERS, Graminor, INRA and DANKO. All trial sites were sown under the same complete block design with three replications. The trials were cut under a Conservation/Silage cut protocol, with two silage cuts and three aftergrass cuts. The Irish trial (which is the subject of this paper) was sown in May 2013 and is located in Athenry, Co. Galway, adjacent to the DAFM National List/Recommended List trials (53°18'N, 8°45'W), on a peaty loam soil. Nitrogen (N) fertiliser was applied at a rate of 350 kg ha^{-1}. Applications of phosphorous, potassium and sulphur were as indicated by annual soil analysis to meet growth requirements.

Field plots of 11.41 m^2 were harvested using a Haldrup plot harvester at cutting heights of 5-7 cm. Total plot yield was recorded and a subsample (*circa* 300 g) was oven-dried at 80 °C for 16 hours to determine DM yield. Dried samples from the first (silage) cuts in mid-May were analysed utilising established wet chemistry methods at Teagasc, Grange, where a subsample was dried at 40 °C for 48 h, milled through a 1 mm screen and analysed for *in-vitro* DM digestibility (DMD; Tilley and Terry, 1963), crude protein (CP; using the LECO FP-628 nitrogen analyser, AOAC 1990), water soluble carbohydrates (WSC; anthrone method; Thomas, 1977) and buffering capacity (BC; Playne and McDonald, 1966). Ground cover scores on a 1 to 9 scale were recorded by visual assessment at the end of each harvest year. Total DM yield, individual cut yields, quality data and ground cover scores for the three harvest years were analysed by variety and by hybrid group. The explanatory effects in the analysis were variety or hybrid group with block, year and interaction with year. The model was fitted using the Mixed procedure in SAS 9.4 (SAS, 2014). Correlation between years was modelled using a repeated measures covariance structure. Means for significant effects were compared using a simulation procedure to account for multiplicity effects and residual checks were made to ensure that the assumptions of the analysis were met.

Results and discussion

Harvest Year had a significant influence on total annual DM yield, with the trial average ranging from 13.7 t ha^{-1} in 2016, 15.8 t ha^{-1} in 2017, to 17 t ha^{-1} in 2015. This annual variation also applied to the quality measurements. Results are presented for Hybrid Type in Table 1, with control varieties Fa6x, Fp2x, Lm2x, Lm4x, Lp2x, & LP4x. The LmFp ($n = 8$), LmFg ($n = 1$), and LmFa ($n = 3$) hybrids have yield and quality values clustered around those of the diploid and tetraploid Italian controls. A similar yield and quality cluster applies to LpFp ($n = 3$) hybrids, closely matching the Lp2x and Lp4x ryegrass controls. Ground Cover scores do not appear to be as influenced by year, with cover for each hybrid type relatively stable in the years examined. As with yield and quality, the hybrid types demonstrated cover scores similar to the ryegrass component of their parentage. Similar observations were reported by Ghesquière *et al.* (2016).

Conclusion

Festulolium varieties, using Italian or perennial ryegrass parentage, are capable of producing silage yields and quality at least as good as existing ryegrasses with satisfactory ground cover under Irish conditions.

Table 1. Dry matter yield, dry matter digestibility (DMD), water soluble carbohydrate (WSC), crude protein (CP), buffer capacity (BUF) and ground cover scores by Festulolium hybrid type. Data is derived from three harvest years, 2015 - 2017.

Hybrid Type	Cut 1	Cut 2	Cut 3	Cut 4	Cut 5	Total	DMD	WSC	CP	BUF	G C
	t ha^{-1}	t ha^{-1}	t ha^{-1}	t ha^{-1}	t ha^{-1}	t ha^{-1}	g kg^{-1} DM	g kg^{-1} DM	g kg^{-1} DM	g kg^{-1} Meq	1 - 9
Fa6x	6.35	4.02	1.92	1.20	0.46	13.95	696.70	142.10	105.11	360.03	4.67
Fp2x	5.26	3.54	2.02	1.37	0.51	12.70	730.55	129.92	125.63	394.28	4.78
Lm2x	7.78	4.60	1.93	1.48	0.59	16.38	722.58	269.45	82.40	284.02	4.17
Lm4x	7.71	4.59	2.17	1.76	0.65	16.88	716.94	280.82	77.92	287.84	4.33
LmFa	7.74	4.96	1.71	1.48	0.54	16.43	712.85	241.67	79.85	308.00	3.33
LmFg	6.15	4.20	2.05	1.45	0.52	14.37	689.96	152.22	105.59	361.44	2.72
LmFp	7.85	4.61	1.81	1.49	0.54	16.30	713.96	221.00	83.27	312.99	4.30
Lp2x	7.16	4.41	1.97	1.43	0.72	15.69	749.09	218.39	98.72	302.34	6.17
Lp4x	6.59	4.64	1.99	1.58	0.73	15.54	760.67	231.35	96.48	329.90	6.00
LpFp	7.22	3.92	1.78	1.27	0.68	14.88	737.67	205.35	93.51	312.24	5.87
Mean	6.98	4.35	1.94	1.45	0.59	15.31	723.10	209.23	94.85	325.31	4.63
s.e	0.45	0.24	0.11	0.074	0.033	0.75	7.60	12.8	4.84	19.27	0.36
Main effect *P* -value	<0.001	<0.001	0.06	<0.001	<0.001	0.004	<0.001	<0.001	<0.001	0.01	<0.001
Interaction with year	Y	Y	Y	Y	Y	Y	Y	N	N	N	Y

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The productivity of multi-species swards using three nitrogen fertilisation rates

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Abstract

Field trials were carried out with the aim to study the forage yield and botanical composition of grass and legume–grass swards fertilised with three nitrogen rates (N0, N60, and N120) in two production years. Twelve mixed multicomponent swards were composed of *Phleum pratensis, Dactylis glomerata, Festuca pratensis, Festuca arundinacea, Festuca rubra, Festulolium, Lolium perenne, Lolium boucheanum, Trifolium pratense, Medicago sativa* and *Galega orientalis*. A three-cut sward management protocol was used. On average, for the three investigation sites, increasing the N fertiliser application rate from 0 to 120 kg ha^{-1} contributed to a significant dry matter (DM) yield increase: by 3.55 t ha^{-1} in the first year of harversting and by 2.76 t ha^{-1} in the second year of harversting. The results show a substantial decrease in DM yields between the first and second year of harversting for swards containing only grass and grass – *Trifolium pratense* swards. More stable productivity was demonstrated by swards containing *Medicago sativa* and *Galega orientalis*.

Keywords: grass-legume mixture, nitrogen fertilisation, cutting, production year

Introduction

Use of efficient legume-containing multispecies swards can provide high quality forage. In Latvia's farms, the use of multicomponent grass – legume mixtures is a traditional practice, because these swards can secure good persistence and more stable productivity (Adamovics *et al*., 2006). Use of nitrogen fertilisation results in an increase of the dry matter yield of grass – legume mixtures but at the same time it has a negative effect on the proportion of legumes in mixtures (De Vliegher and Carlier, 2008; Soegaard and Nielsen, 2012; Meripold *et al.*, 2016). The objective of this research was to determine the influence of nitrogen fertilisation on the performance of multicomponent swards in two production years for the production of herbage in a cutting system under the agro-climatic conditions of Latvia.

Materials and methods

Field trials were conducted at three experimental sites in Latvia on soil types: sod-calcareous soils (pH_{KCl} 6.7, phosphorus (P) 60 mg kg^{-1}, potassium (K) 144 mg kg^{-1}, and organic matter 24 - 28 g kg^{-1} of soil), sod-podzolic soils (pH 7.1, P 253 mg kg^{-1}, K 198 mg kg^{-1}, organic matter 31 g kg^{-1}), and sod stagnogley soil (pH 6.33, P 93 mg kg^{-1}, P 111 mg kg^{-1}, organic matter 23 g kg^{-1}). Twelve mixtures based on the species *Phleum pratensis, Dactylis glomerata, Festuca pratensis, Festuca arundinacea, Festuca rubra, Festulolium, Lolium perenne, Lolium boucheanum, Trifolium pratense, Medicago sativa*, and *Galega orientalis* were used in all experimental sites. Mixtures were sown in June 2014 without a cover crop, in three replications, within a 10 m^2 plot size. The mixtures were grouped in four sward types: only grasses (G); lucerne (*Medicago sativa*) and grass mixture type (Ms+G); red clover (*Trifolium pratense*) and grass mixture type (Tp+G); galega (*Galega orientalis*) and grass mixture type (Go+G). The following fertilisation treatments were used for all mixtures: P78, K90 and N0, $N60_{(30+30)}$ and $N120_{(60+60)}$ kg ha^{-1}. Swards were cut three times during the vegetation season. The botanical composition (legumes, grasses and herbs) and the yields were determined after each cutting. The average data of the three experimental sites were statistically analysed using the three-way analysis of variance with 'mixture type', 'fertiliser', and 'year of sward use' as factors, and the difference among means was detected by LSD at the $P < 0.05$ probability level (Excel for Windows, 2003).

Results and discussion

The influence of the levels of nitrogen fertilisation on the increase in DM yield was closely connected with the botanical composition of swards (Table 1). The N rate increase from 0 to 120 kg ha^{-1} contributed to a significant DM yield increase in both production years for all mixture types. Highest DM yield increase was stated for grass-only swards (by 6.11 t DM ha^{-1} at first, and 4.92 t DM ha^{-1} at second year).

For all legume-containing mixture types, N application negatively affected the proportion of legumes in the sward compared to unfertilised plots in both production years (Figure 1). Swards containing lucerne (Ms+G) had to lowest decrease in legume content (on average 6.3% over two years) compared with the other treamtments. Stability in legume content in Ms+G swards contributed to it having the highest total DM yield over two production years (35.85 t ha^{-1}). The application of N fertiliser contributed to a larger legume content decrease in Go+G and Tp +G swards (by 12.2 and 12.0%, respectively). The forb

Table 1. Average dry matter yields of grass-only and grass-legume swards yield for two years of sward use, t DM ha^{-1}.

Year of sward use (year)	Mixture type (MT)	N rate, kg ha^{-1} (N)			
		N0	N60	N120	Mean
First	G	10.04	13.48	16.15	13.22
	Ms+G	16.64	17.79	19.36	17.93
	Tp+G	20.06	19.89	20.94	20.29
	Go+G	11.45	13.71	15.92	13.69
	Mean	14.55	16.22	18.09	16.29
Second	G	4.84	7.64	9.76	7.42
	Ms+G	17.09	17.52	19.14	17.91
	Tp+G	11.88	13.89	14.09	13.28
	Go+G	11.24	12.45	13.12	12.27
	Mean	11.26	12.88	14.03	12.72

$LSD_{0.05}$ MT = 0.57; N= 0.29; Year = 0.23; MT/N = 0.99; MT/Year = 0.81; N/Year = 0.40; MT/N/Year = n.s.

LSD = least significant difference; n.s. = not significant.

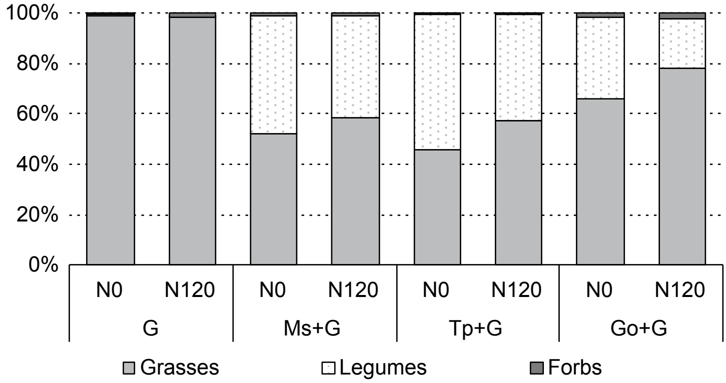

Figure 1. Proportions of the groups of herbage species (%) applying two fertilisation rates (on average three soil types in two production years): G: grasses; Ms+G: lucerne, grass; Tp+G: red clover, grass; Go+G: galega, grass.

proportion (0.7 - 2.7%) in all sward types was low in both years of sward use. Significant N application effects on forb content were not stated.

Our results show substantial decrease in DM yield between the first and second year of harversting. The maximum yield was obtained in the first year of sward use (on average 16.29 t ha^{-1}).

The difference in DM yield between two production years was more affected by the type of seed mixture than by applied N-level. At N0 level, sward productivity decrease between the two years of harversting was (on average for mixture types) 3.29 t ha^{-1} or 23%. A similar productivity decrease (by 3.34 t ha^{-1} or 21%) was stated for N60 fertilised swards. Due to the highest total productivitity at N120 level, average yield decrease was more expressed at the absolute scale (by 4.07 t ha^{-1}) but not at the relative scale (by 22%). Sward productivity in successive years of harversting was substantially different between mixture types. For swards containing only grass, the DM yields in the second production year decreased by 5.80 t ha^{-1} or 44%. Rapid decline in productivity (by 35%) was observed for Tp+G mixture type. A considerably lower drop in productivity, by 1.42 t ha^{-1} or 10%, between the first and second production year was found for Go+G mixture type. Stable productivity was demonstrated by Ms+G swards, where significant differences between the yield of two production years were not found.

Conclusion

The positive influence of N fertilisation on DM yields was closely connected with the botanical composition of swards. Dry matter yield increase was better expressed on swards with high proportion of grass. The application of N fertiliser contributed to decrease in the proportion of legumes in swards. The decrease in legume content was less expressed for Ms+G sward. More stable yield over the two years demonstrated Ms+G and the Go+G mixture types.

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Sward structure and biological nitrogen fixation potential of perennial ryegrass-white clover swards

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Abstract

Sward composition and canopy structure can alter grazing dynamics. The objective of this study was to investigate the effect of perennial ryegrass (*Lolium* perenne L.) ploidy and white clover (*Trifolium repens* L.) inclusion on sward structure and biological nitrogen (N) fixation (BNF) throughout the grazing season under a high N fertiliser regime (250 kg N ha^{-1}) and a high stocking rate (2.75 livestock units ha^{-1}). The study was a 2 × 2 factorial design, consisting of two perennial ryegrass ploidies (diploid, tetraploid) and two white clover treatments (grass-clover, grass-only). Four sward treatments (diploid only, tetraploid only, diploid + clover, tetraploid + clover) were compared over a full grazing season. Perennial ryegrass ploidy had a significant effect on leaf proportion, tiller density, sward white clover content, tiller weight and leaf area. Diploid swards had lighter tillers (-0.07 g), smaller leaves (-0.78 cm^2), lower leaf proportion (-7%), greater tiller density (+1,225 tillers m^{-2}) and higher white clover content (+8%) than tetraploid swards. White clover inclusion had a significant effect on leaf (-7%) and stem (+5% pseudostem, +4% true-stem) proportions, tiller density (-1,649 tillers m^{-2}) and BNF (+151 kg N ha^{-1}). Altering sward composition using ploidy and white clover can affect sward canopy structure and grazing dynamics.

Keywords: *Trifolium repens* L., *Lolium perenne* L., perennial ryegrass ploidy, stolon morphology, biological nitrogen fixation

Introduction

Grazed herbage is the cheapest source of feed for ruminant production systems (Finneran *et al.*, 2012), and the utilisation of increased quantities of grazed herbage on-farm can provide the basis of sustainable livestock systems. Perennial ryegrass (*Lolium perenne* L.: PRG) dominates temperate grass-based systems as it provides high nutritive value feed for livestock, good grazing persistence and maintains a high regrowth capacity (Wilkins and Humphreys, 2003). The inclusion of white clover (*Trifolium repens* L.: WC) in PRG swards can increase herbage growth rates (Frame and Newbould, 1986), maintain high nutritive value (Beever *et al.*, 1986) and improve animal intake (Ribeiro Filho *et al.*, 2005). However, many studies suggest that WC in grass-clover (GC) swards does not persist under high nitrogen (N) fertiliser use (> 200 kg N ha^{-1}) and high stocking rates (> 2.5 livestock units (LU) ha^{-1}; Frame and Newbould, 1986). Previous studies on WC inclusion in grass-based systems have concentrated on agronomic aspects, animal nutritional aspects and environmental aspects. There is little information on the structural characteristics that contribute to grazing dynamics under high N fertiliser use (> 200 kg N ha^{-1}) and high stocking rates (> 2.5 LU ha^{-1}). The objective of this study was to investigate the effect of PRG ploidy and WC inclusion on sward structure and BNF, over a full grazing season, under those conditions.

Materials and methods

The swards used in this study form part of a larger farm system's study to examine the effect of PRG ploidy and WC inclusion on dairy production systems. The study was undertaken at Teagasc, Clonakilty, Co. Cork, Ireland and was a 2 × 2 factorial design. The study consisted of two PRG ploidies (tetraploid, diploid) and two WC treatments (GC, GO) resulting in four sward treatments (diploid only, DO, tetraploid only, TO, diploid + clover, DC, tetraploid + clover, TC). Twenty blocks of four paddocks were created, balanced for location, topography and soil type and treatments were randomly assigned in each block. For this study, three blocks of four paddocks were used. All treatments were stocked at 2.75 dairy cows ha^{-1} and rotationally grazed. Weekly monitoring of farm herbage cover within each treatment was undertaken using PastureBase Ireland (Hanrahan *et al.*, 2017) to produce a weekly grass wedge during the grazing season. Target post-grazing sward height was 3.5 - 4.0 cm during the first and last rotations and 4.0 - 4.5 cm during the main grazing season. Inorganic N fertiliser was applied at 250 kg N ha^{-1} $year^{-1}$ across all treatments between mid - January and mid - September. Measurements included sward WC content, tiller density, stolon mass, tiller morphology (leaf, stem, dead proportion, leaf area) and post-grazing sward height. Biological N fixation was estimated using the N difference method (Munro and Davies, 1974); BNF was estimated by calculating the difference between N yields of GC and GO swards within the same block: Amount of N fixed = Total N yield in GC swards – Total N yield in GO swards. Data were analysed using Mixed Models in SAS (SAS, 2011). Terms included in the model were PRG ploidy, WC inclusion, block, rotation and the PRG ploidy × WC interaction.

Results and discussion

Tiller density differed significantly between PRG ploidies (Table 1; $P < 0.001$) and with WC inclusion ($P < 0.001$). Diploid swards had a greater tiller density than tetraploid swards (diploid: 5,579 tillers m^{-2}; tetraploid: 4,354 tillers m^{-2}) and WC inclusion reduced tiller density (GO: 5,792 tillers m^{-2}; GC: 4,143 tillers m^{-2}). Perennial ryegrass ploidy had a significant effect on leaf proportion ($P < 0.01$), tiller weight ($P < 0.01$) and leaf area ($P < 0.05$). Tillers in diploid swards were lighter (-0.07 g), had smaller leaves (-0.78 cm^2) and a lower leaf proportion (-7%) than tillers in tetraploid swards. Tillers in GC swards had lower leaf proportions ($P < 0.01$; -7% leaf) and greater stem proportions ($P < 0.01$; +5% pseudo-stem, +4% true-stem) than tillers in GO swards. Grass-clover swards fixed 151 kg N ha^{-1}. Perennial ryegrass ploidy had a significant effect on sward WC content (Figure 1; $P < 0.05$; DC: 29%; TC: 21%).

Conclusion

Sward WC content was higher in diploid swards and the lower tetraploid sward tiller density promoted a lower post-grazing sward height which may have removed more WC from these swards. Tetraploid and diploid swards differed in sward canopy structure; tetraploid swards appear to be more efficient in terms of grazing ease (lower post-grazing sward height). Grass-clover swards fixed biological N, indicating the potential to reduce N fertiliser use. Altering sward composition using PRG ploidy and WC affected sward canopy structure and grazing dynamics.

Table 1. Structural characteristics of each sward type.

Sward characteristics	TO	DO	TC	DC	Ploidy	WC
Tiller density (m^{-2})	4,631	6,952	4,079	4,206	0.001	0.001
Stolon mass (g m^{-2})			70.3	85.4	N.S.[1]	
Leaf proportion	0.70	0.66	0.65	0.56	0.01	0.01
Pseudo-stem proportion	0.14	0.17	0.17	0.22	0.01	0.001
True-stem proportion	0.06	0.05	0.07	0.02	N.S.	0.05
Dead proportion	0.10	0.13	0.10	0.13	0.05	N.S.
Leaf area (cm^2 $leaf^{-1}$)	4.27	3.24	3.79	3.37	0.05	N.S.
Tiller weight (g)	0.41	0.32	0.44	0.37	0.01	N.S.
Post-grazing sward height (cm)	3.91	4.31	3.68	4.1	0.001	0.05

[1] N.S. = not significant.

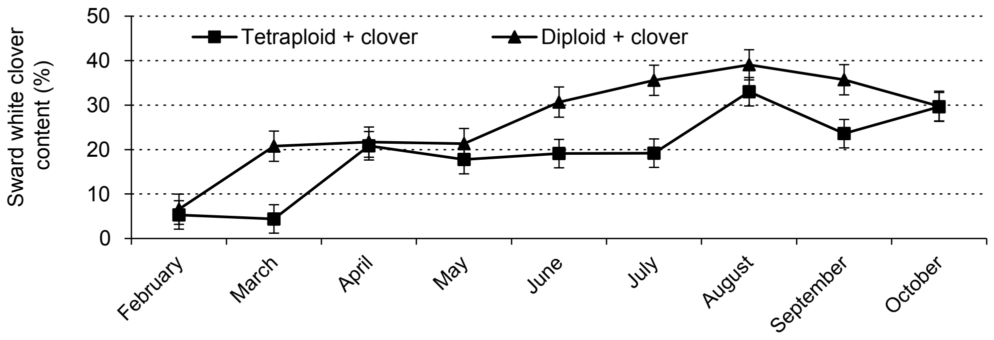

Figure 1. Average sward WC content across all measurement dates for each GC sward (tetraploid + clover and diploid + clover), expressed by mean values; standard error represented by error bars.

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Evaluation of potential of forage legume leaves as a protein source for organic pig farms

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Abstract

Present research in animal nutrition within the European region is looking for 'home-made' protein sources to avoid high dependency on imported soybean protein. The main objective of this study was, therefore, to investigate the potential for organic production of legume leaves as a protein source for pig nutrition. In 2017, production of leaves per hectare was estimated through forage sampling in the common stands of a lucerne (*Medicago sativa* L.) – red clover (*Trifolium pratense* L.) mixture growing under organic management. Number of stems, maximal stem length and leaf weight ratio on a DM basis was assessed for both species in the samples where total DM and leaf production were calculated. Lucerne contributed more to the total annual DM yield of the mixture whilst red clover reached a significantly higher leaf weight ratio. Quality of leaves from bales of harvested hay seems to be acceptable for pig nutrition under organic management. This research has indicated that a lucerne – red clover mixture can be an effective field source of leaf protein.

Keywords: alfalfa, red clover, mixture, leaf separation

Introduction

The difference between high protein demands by the livestock sector and low protein production in the European Union (EU) has resulted in the fact that most of the protein for livestock production in the EU is imported, mainly from South America in the form of the soybean meal (Van Krimpen *et al.*, 2013). Apart from sensitivity of animal production to price volatility, most of the imported soya bean meal is genetically modified which can be a concern with regard to organic farming systems (Westhoek *et al.*, 2011). For these reasons, present research in this scientific area is looking for 'home-made' protein sources based on common field crops within the EU. Forage legumes play a key role in integrating livestock and crop production and are considered as a potential protein source (Solati *et al.*, 2017). In line with this target, the goal of the current project in the Rural Development Programme in the Czech Republic is the development of technology for forage legume leaf separation and to evaluate the potential of this product as an organic protein source for pig nutrition. This paper summarises the initial part of the project and includes the first year results from a field trial comparing the productivity of a lucerne (*Medicago sativa* L.) – red clover (*Trifolium pratense* L.) mixture and the mean nutritive value of leaf products for pig nutrition.

Materials and methods

A field experiment established a lucerne – red clover mixture growing under organic management in the first harvest year. The organic farm is located at Sasov near Jihlava in the Czech Republic. In 2017, production of leaves per hectare was estimated through forage sampling in the common stands of a lucerne – red clover mixture (sown in April 2016, seeding ratio 50:50) harvested three times per year. Before each cut, samples were clipped using a hand scissors, to a height of 50 mm above the ground from an area of 12.5 × 50 cm in four replicates. All weeds were separated from the sample and the number of stems (stem density, SD m^2) and length of the longest stem (MSL, m) were determined for lucerne and red clover. Five of the longest stems of each legume species in the sample were selected and their leaves (blade, petiole, stipule) were separated by hand from the stems (stem, bud, flower). All samples were oven dried at 60 °C to constant DM. The lucerne and red clover leaf weight ratio (LWR, g kg^{-1} DM), leaf dry matter yield and total dry matter yield (DMY, g m^{-2}) as well as percentage of weeds were calculated. A mixed sample of 1 kg of hay was taken from the bales at the third cut. Leaves were separated by hand from stems and these samples were analysed for crude protein, crude fibre, ash, fat, and nitrogen free extract (g kg^{-1}) in the laboratory of the Institute of Animal Science Prague. Metabolisable energy (MJ kg^{-1}) was assessed for pig nutrition based on chemical composition of the leaves and stems. Field data were analysed by one-way analysis of variance (ANOVA) within each cut comparing differences in the contribution of lucerne and red clover in the mixture.

Results and discussion

The contribution of lucerne and red clover varied over the growing season (Table 1). Stem density and DMY ratio of red clover was significantly lower in the second and third cut. Summer and early autumn represents the drier period of the growing season for this site. The decrease in red clover content over the season is in line with Peterson *et al.* (1992), who stated that these two crops have complementary production responses to climatic conditions, where lucerne is higher yielding in dry conditions, whilst red clover is higher yielding in wet conditions. In spite of lower DMY, red clover exhibited a higher LWR in the second and third cut which partially eliminated the decrease in leaf DMY. Total DMY ranged from 453 to 810 g m^{-2} with minimal weed content. Leaf DMY values ranged from 186 to 347 g m^{-2} which represent a total annual leaf DMY of around 750 g m^{-2}. This seems to be a higher DMY than that reported for grain legume production under organic management. It is in accordance with Solati *et al.* (2017) who considered that red clover and lucerne are favourable species for protein production in the EU. It can be concluded that a mixture with both species can give some advantages in this regard due to the higher productivity of lucerne and higher LWR of red clover.

Increasing forage based protein that can be grown 'on-farm' is one way of addressing the EU protein deficit and increasing the efficiency of livestock production. Lucerne leaves have been reported to have a more suitable profile of crude protein fractions than stems (Hakl *et al.*, 2016) which is promising for their protein value. Biomass from hay bales at the third cut contained 610 g kg^{-1} of legume leaves after manual separation, in line with values of LWR of both species in the field samples (Table 1). The hay was baled at a moisture content of around 50% and drying of these bales was realised by utilising waste heat from a biogas plant. It seems to be an appropriate technology to maintain a high LWR in the harvested forage. Chemical composition of forage parts and calculated metabolisable energy is reported in Table 2. There was a clear difference between the quality of plant parts, with leaves having a higher feeding value. The leaf crude fibre content was higher (148 g kg^{-1}) in comparison to common values in pig diets (30 - 80 g kg^{-1}). A mean crude protein value for lucerne leaves of 306 g kg^{-1} over the growing season has been

Table 1. Agronomic traits of lucerne (LU) – red clover (RC) mixture stand over three cuts in 2017.

	1.cut			2.cut			3.cut		
	LU	RC	*P*-value	LU	RC	*P*-value	LU	RC	*P*-value
Stem density (pcs m^{-2})	392	468	0.433	508	180	0.023	404	136	0.001
Maximal stem length (cm)	74	56	0.016	50	33	0.095	53	32	0.003
Leaf weight ratio (g kg DM^{-1})	416	440	0.620	370	518	0.218	402	767	<0.001
Dry matter yield ratio (%)	49	50	0.902	76	23	0.001	69	31	0.020
Leaf dry matter yield (g m^{-2})	167	180	0.751	136	50	0.015	127	98	0.335
Leaf dry matter yield ratio (%)	48	52	-	72	23	-	56	44	-
Weeds (% DMY)	<1		-	1		-	<1		-
Total dry matter yield (g m^{-2})	810		-	482		-	453		-

Table 2. Chemical composition of leaves and stems and metabolisable energy calculated for pig nutrition (plant parts were separated by hand from hay bales at 3rd cut).

Plant part	Crude protein ($g\ kg^{-1}$)	Crude fibre ($g\ kg^{-1}$)	Ash ($g\ kg^{-1}$)	Fat ($g\ kg^{-1}$)	Nitrogen free extract ($g\ kg^{-1}$)	Metabolisable energy ($MJ\ kg^{-1}$)
Leaves	245	148	135	12	459	9.78
Stems	139	359	96	6	399	4.67

reported by Hakl *et al*. (2016) which shows that a higher protein value of legume leaves can be obtained than the results shown in Table 2.

Conclusion

Results indicate that forage legume crops can be an effective field source of rich protein leaves under organic management. Leaf quality cannot compete with soybean meal due to higher fibre contents but seems to be acceptable as pig nutrition for organic farms. Further investigation will provide valuable information on quality changes over the growing season, amino acid profile and effectiveness of technology for leaf separation.

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Match clover: optimal selection of clover species

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Keywords: forage species suitability, climatic, edaphic, *Trifolium*

Introduction

Clover species (*Trifolium* spp.) selection is an important management decision for forage production and soil improvement (Ball and Lacefield, 2000). The information currently available to guide species selection is generalised to the point of being unhelpful for specific locations and uses. The information is descriptive and qualitative rather than the quantitative data that is required for computer-based solutions for any location. Developing a quantitative database of clover species information and layering with geographic information system (GIS) information will allow comparisons between the conditions of a specific location and species characteristics (Hannaway *et al*., 2009). Framing these components within a simple-to-use web application will provide an effective tool for appropriate global use of forage legumes.

Materials and methods

This project defines the climatic and edaphic quantitative tolerances of clover species using GIS-based mapping technologies to identify geographically suitable zones and define management requirements.

Results and discussion

A template for key qualitative and quantitative information has been developed, including: quantitative tolerances for precipitation, temperature ranges, soil pH, salinity, and drainage, seasonal and annual productive potential, growth habit, suitability for beef, sheep, dairy, and horse pastures, hay and silage, and cover/green manures. Species include red, white, crimson and arrowleaf clovers. Other clovers will be added as co-operators advise.

Conclusion

This web-based decision support segment, which is in development, will provide a unique combination of computer and experience-based decision making for optimal clover species selection.

Acknowledgements

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Development and persistence of reseeding legumes in permanent grassland under different cutting and fertilisation intensity

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Abstract

Legumes can be used to increase the protein yield of grassland. With higher protein yields, animal nutrition would not be dependent on genetically modified soybeans. The establishment of legumes in intensive dairy systems is difficult because of high nitrogen levels and frequent use of liquid manures. Therefore, establishment and persistence of red (*Trifolium pratense*) and white clover (*Trifolium repens*) in permanent grassland were tested at different rates of mineral and organic nitrogen fertilisers (0, 42, 85, 170 kg N ha^{-1}) and at different cutting frequencies (3 and 5 cuts year^{-1}). Dry matter and protein contents of the produced roughage were analysed. First results show that red clover establishes more successfully in permanent grassland than white clover. Reseeding of red clover resulted in higher DM and protein yields compared to white clover. Use of red clover under low nitrogen resulted in higher protein yields compared to high nitrogen fertilisation without reseeding.

Keywords: legume, crude protein, slot seeding, grassland, fertilisation

Introduction

Protein required for livestock farming is usually not available in sufficient quantities from permanent grassland. Establishment of legumes could be a possibility to close this 'protein gap'. Additionally, this approach takes the customer's desire for non-GMO food into account. In intensive dairy systems with high nitrogen fertilisation, the presence of legumes in grassland swards is low and the possibilities to establish legumes are poor. High amounts and frequent application of slurry or mineral N inhibit the establishment of legumes strongly. For this reason, reseeding of legumes in swards instead of N fertilisation might be of great interest. Further studies by Nyfeler *et al.* (2009) or Luescher *et al.* (2014) show that legume-grass mixtures can achieve higher dry matter yields like grass monocultures with high N efficiency. Red clover portions decrease with time after a good youth development (Marshal *et al.*, 2014). Mixed swards with red clover showed a better performance in yield and quality than grass based even if they are cut four times per year up to three years (Hejduk, 2015). It is not yet clear if there are differences between establishment and persistence of red clover and white clover when fertilised with different rates of mineral and organic N (0, 42, 85 and 170 kg N ha^{-1}) and under different cutting intensity (three or five cuts per year).

Material and methods

The experimental site was located in the south of Germany (Baden-Wuertemberg). Prior to the start of experiment in 2014, the composition of the intensive permanent grassland consisted of around 90% grasses (mainly *Lolium hybridum* and *Phleum pratense*), 6% forbs (*Taraxaum officinale, Plantago lanceolata*) and 4% white clover. The experiment was carried out in a multi-factorial, incomplete randomised block design testing effects of (1) reseeding, (2) fertiliser intensity, (3) cutting frequency and (4) fertiliser type on the establishment of reseeded legumes. Every factorial combination was repeated three times with a plot size of 10 m^2. Data from 2015 and 2016 are presented here and three and five cuts were compared. 'Fertiliser intensity' was compared in three steps: 'without nitrogen fertiliser', '35%' and '75% of nitrogen fertilizer demand' where the demand is based on the common fertilisation system of Baden-Wuerttemberg for permanent grassland with 245 kg N ha^{-1} for 5 and 120 kg N ha^{-1} for three cuts.

'Fertiliser type' compared 'mineral fertiliser' with 'cattle slurry' (average mineral content of the slurry in kg m^{-3}: 2.3 N, 0.6 P, 2.4 K). Amounts of minerals were similar for organic and mineral fertilisation. Due to farm-scale liquid manure technology with a trail hose applicator, not all factor combinations could be considered. In the case of three cuts, the treatment 35% of the N requirement is not included and with five cuts the 75% of the N requirement with organic fertilisation had to be supplemented by a mineral fertilisation. The mineral fertilisation was applied from the first to the third growth and the liquid manure was applied to the first and second growth.

'Reseeding' was done with a slot seeder with the levels 'without', 'white clover (seed rate 10 kg ha^{-1})' and 'red clover (20 kg ha^{-1})' after harrowing to open the sward in May 2014. Seed rates are in accordance with results of previous experiments and the different thousand grain weight (Elsaesser *et al.*, 2014). Success of the legume reseeding was scored five weeks after reseeding with an assessment scheme where 1 = no, 2: few, 3: several, 4: scattered lines, 5: several parallel lines of seedlings visible. The yield proportions of grass, herbs and legumes are estimated visually in the field with botanical analysis after Klapp (1965). Dry matter yields were measured and the protein contents were analysed by NIRS. Statistical analysis was performed with Excel 2010 and R (R Development Core Team, 2008).

Results and discussion

White and red clover established well in 2014 and did not differ within N treatment (Figure 1). With higher N fertilisation legume establishment failed. At 170 kg N ha^{-1} the establishment of the legumes was significantly lower compared to nil N (five cuts). The effect of fertilisation appears to be more pronounced on white clover than on red clover. Nitrogen fertilisation is particularly beneficial for grasses which compete with the legumes and have a negative effect on the low-growing white clover.

The observed effect of nitrogen rate on the establishment is continued in the proportions of the legumes in the subsequent harvest years. Thus, white clover obtained proportions of up to 50% and red clover up to 90% of the herbage in the unfertilised plots. Higher percentages were observed in the later growths. When high amounts of N were applied, the yield of white clover decreases below 20% and red clover to less than 60% of the herbage. Despite high cutting frequency, red clover retained very high yield proportions. The amount of N fertilisation had no significant influence on dry matter and crude protein yield within reseeded plots (Table 1). This might be caused by decreasing legume percentages with higher N fertilisation. Regarding dry matter and crude protein yields it seems that nitrogen can be substituted by legumes and close nearly the 'protein gap'. A study of Mallarino *et al.* (1990) shows that N fixation by white and red clover follows linearly the proportions of legumes.

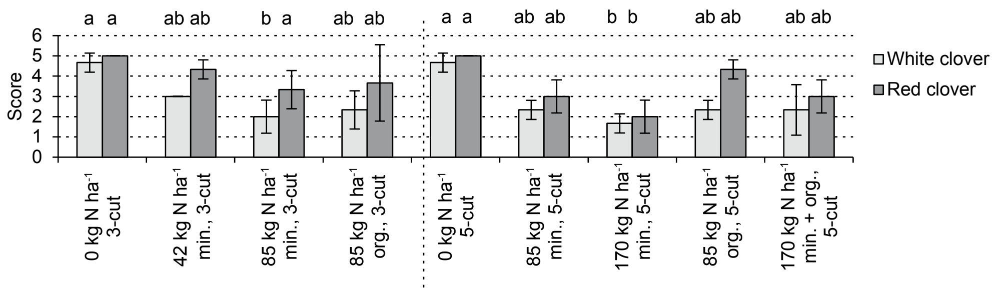

Figure 1. Average scores of the reseeded species over the fertiliser intensity at three (left) and five cuts (right). The bars show the standard deviation of the three replications. Different letters indicate significant differences ($P < 0.05$) between fertilisation at a cutting frequency.

Table 1. Mean dry matter (DM) and crude protein yields (CP) in t ha^{-1} with standard deviation from 2015 and 2016. Different letters indicate a significant difference with $P < 0.05$.[1]

		Rates of fertilizer	Reseeding								
			Without			White clover			Red clover		
DM (t ha^{-1})	3-cuts	0 kg N ha^{-1}	7.65 ± 0.86	a	AB	11.4 ± 1.5	a	A	14.3 ± 1.4	a	B
		42 kg N ha^{-1}, min.	7.41 ± 0.49	a	A	9.5 ± 0.5	a	AB	14.3 ± 1.0	a	B
		85 kg N ha^{-1}, min	9.68 ± 0.82	a	A	9.4 ± 0.9	a	A	14.2 ± 1.3	a	A
		85 kg N ha^{-1}, org.	10.82 ± 0.88	a	A	13.2 ± 3.8	a	A	13.6 ± 0.8	a	A
	5-cuts	0 kg N ha^{-1}	8.29 ± 1.91	a	A	10.3 ± 1.23	a	A	15.7 ± 0.9	a	B
		85 kg N ha^{-1}, min	8.64 ± 0.5	a	A	11.08 ± 1.27	a	A	13.9 ± 1.1	a	A
		170 kg N ha^{-1}, min.	10.16 ± 0.5	a	A	10.97 ± 0.9	a	A	13.6 ± 1.8	a	A
		85 kg N ha^{-1}, org.	8.86 ± 1.07	a	A	11.63 ± 1.19	a	AB	16.2 ± 1.2	a	B
		170 kg N ha^{-1}, org.	10.45 ± 0.65	a	A	11.87 ± 1.33	a	A	14.5 ± 1.3	a	A
CP (t ha^{-1})	3-cuts	0 kg N ha^{-1}	0.88 ± 0.17	a	A	1.4 ± 0.18	a	AB	2.19 ± 0.20	a	B
		42 kg N ha^{-1}, min.	0.89 ± 0.14	a	A	1.13 ± 0.06	a	A	2.10 ± 0.19	a	B
		85 kg N ha^{-1}, min	1.02 ± 0.1	a	A	1.21 ± 0.18	a	A	2.04 ± 0.16	a	A
		85 kg N ha^{-1}, org.	1.15 ± 0.13	a	A	1.62 ± 0.31	a	AB	2.01 ± 0.27	a	B
	5-cuts	0 kg N ha^{-1}	1.26 ± 0.31	a	A	1.79 ± 0.19	a	A	2.79 ± 0.13	a	B
		85 kg N ha^{-1}, min	1.25 ± 0.10	a	A	1.87 ± 0.26	a	AB	2.55 ± 0.20	a	B
		170 kg N ha^{-1}, min.	1.68 ± 0.07	a	A	1.82 ± 0.12	a	A	2.47 ± 0.42	a	A
		85 kg N ha^{-1}, org.	1.45 ± 0.24	a	A	2.05 ± 0.19	a	A	2.90 ± 0.22	a	B
		170 kg N ha^{-1}, org. + min.	1.55 ± 0.11	a	A	1.88 ± 0.20	a	AB	2.59 ± 0.24	a	B

[1] Small letters characterise the significant differences of fertiliser treatments within reseeding treatments, large letters characterise the significant differences between reseeding variants within fertiliser treatments.

Conclusion

Establishment of legumes is easier if nitrogen fertilisation is reduced. Reseeding of red clover resulted in higher dry matter and protein yields compared to white clover. The interaction of reseeding and fertilisation shows that red clover with low nitrogen rates resulted in higher protein yields than high nitrogen fertilisation without reseeding. The five cut protocol had higher protein yields compared with three cut protocol.

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Herbage and milk production from grass-only and grass-clover swards

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Abstract

Nitrogen (N) fertiliser application to grassland ensures an adequate supply of high quality herbage is available for dairy cows over a long grazing season. Nitrogen fertiliser use is limited under the Nitrates Directive. However, farms with high stocking rates (> 2.5 LU ha^{-1}) have a high feed demand, and N fixed from the atmosphere by white clover (clover; *Trifolium repens* L.) can supply extra N for herbage growth. Previous Moorepark research has shown that including clover in grazed swards, even at N application levels above 150 kg N ha^{-1} can increase herbage production. A farm systems experiment was undertaken at Teagasc, Moorepark, Ireland from 2013 to 2016. The experiment compared herbage and milk production from a grass-only sward receiving 250 kg N ha^{-1} year^{-1} (Grass250) and grass-clover swards receiving 250 or 150 kg N ha^{-1} year^{-1} (Clover250 and Clover150, respectively). Each treatment was stocked at 2.74 cows ha^{-1}. Annual herbage production was similar on all treatments (14.6 t DM ha^{-1}) across the four years of the experiment. Average annual sward clover content was greater on Clover150 (27%) compared with Clover250 (23%). Milk solids yield was greater ($P < 0.05$) on the Clover250 and Clover150 treatments (496 and 493 kg MS cow^{-1} year^{-1}, respectively) compared with Grass250 (460 kg MS cow^{-1} year^{-1}).

Keywords: white clover, milk production, sward clover content, N application rate

Introduction

Pasture-based milk production systems in temperate regions are generally low cost because grazed grass is the primary feed source for dairy cows (Finneran *et al*., 2012). Nitrogen (N) fertiliser is used in pasture-based milk production systems to ensure an adequate supply of high quality herbage is available to feed dairy cows over a prolonged grazing season (270 + days). Nitrogen fertiliser use is limited under the Nitrates Directive. However, farms with high stocking rates (> 2.5 LU ha^{-1}) have a high feed demand, and N fixed from the atmosphere by white clover (clover; *Trifolium repens* L.) can supply extra N for pasture growth. Enriquez-Hidalgo *et al*. (2016) showed that including clover in grazed swards, even at N application levels greater than 150 kg N ha^{-1} can increase herbage production. Clover grows well with perennial ryegrass (PRG; *Lolium perenne* L.) and is suitable for grazing systems. Perennial ryegrass growth peaks in May/June, while clover growth peaks in August. Clover growth is slower than PRG over winter and in early spring because clover requires soil temperatures of approximately 8 °C for growth while PRG grows at soil temperatures of 5 to 6 °C. Applying N fertiliser to PRG-clover swards can compensate for low clover growth rates in spring. The objective of this experiment was to examine the effect of including clover in PRG swards receiving 150 or 250 kg N ha^{-1}compared to a PRG only sward receiving 250 kg N ha^{-1} on herbage and milk production in an intensive pasture-based spring calving dairy production system.

Materials and methods

A full lactation farm systems experiment (February to November) was undertaken at Teagasc, Moorepark, Fermoy, Co. Cork, Ireland from 2013 to 2016 (four full lactations). The experiment had three treatments: PRG-only receiving 250 kg N ha^{-1} (Grass250), PRG-clover receiving 250 kg N ha^{-1} (Clover250) and PRG-clover receiving 150 kg N ha^{-1} (Clover150). The Grass250 swards were a 50:50 mix of the PRG cultivars Aston Energy and Tyrella sown at a rate of 27.2 kg ha^{-1}. The Clover150 and Clover 250 swards had the same PRG mix as Grass250 plus a 50:50 mix of clover cultivars Chieftain and Crusader sown at a rate of 5 kg ha^{-1}. Treatments received the same quantity of concentrates each year (average 299 kg cow^{-1}), fed in early (February and March) and late lactation (November). Each treatment was stocked at 2.74 cows ha^{-1} in a closed farm system (i.e. the farmlet provided all grazed herbage and silage for the animals in the treatment). Cows were rotationally grazed from early February to the end of November, achieving an average of 8.7 rotations per year. In February of each year, spring-calving Friesian and Friesian × Jersey dairy cows were blocked on calving date, breed, pre-experimental milk yield (MY) (MY for first 2 weeks of lactation), pre-experimental milk solids (MS) yield (as for MY), and parity, and randomly allocated to one of the three treatments. There were 14, 17, 18 and 18 cows per treatment in 2013, 2014, 2015 and 2016, respectively. Cows remained in their treatment groups for the entire lactation. Swards were rotationally grazed to a target post-grazing sward height of 4 cm. Pre-grazing herbage mass was measured with an Etesia mower (Etesia UK Ltd., Warwick, UK) twice weekly. Pre- and post-grazing sward heights were measured daily using the rising plate meter (Jenquip, Fielding NZ). Sward clover content was measured in each Clover250 and Clover150 paddock prior to grazing, as described by Egan *et al*. (2017). Milking took place at 07:30 and 15:30 h daily. Milk yield was measured daily and milk composition (fat, protein) was measured weekly. Data were analysed using PROC MIXED in SAS with terms for treatment, time (week or rotation) and associated interactions. Fixed terms were treatment and week or rotation and random terms were cow and paddock.

Results

Annual herbage production was similar on all treatments (14.6 t DM ha^{-1}) across the four years of the experiment. Average annual sward clover content was greater on Clover150 (27%) compared with Clover250 (23%). Milk yield and MS yield were greater on Clover250 and Clover150 compared to Grass250 (Table 1, Figure 1). Although there was no treatment effect on milk fat and protein content (similar to Enriquez-Hidalgo *et al*., 2014), MS yield was greater on the Clover250 and Clover150 treatments (496 and 493 kg MS cow^{-1}) compared with Grass250 (460 kg MS cow^{-1}) due to increased milk yield (Table 1).

Based on the results of this experiment there is potential to reduce N fertiliser application to PRG clover swards from May onwards in milk production systems with stocking rates up to 2.74 cows ha^{-1}. This offers a considerable potential saving to the farmer in terms of reduced N fertiliser application.

Table 1. Average daily milk and milk solids yield and annual milk solids yield on grass only swards receiving 250 kg N ha^{-1} (Grass250) and grass-clover swards receiving 150 and 250 kg N ha^{-1} (Clover150 and Clover250, respectively) during the experiment (2013 to 2016).

	Grass250	Clover250	Clover150	s.e.m.[1]	*P*-value
Milk yield (kg cow^{-1} d^{-1})	21.47^a	23.05^b	22.57^b	0.335	0.01
Milk protein (g kg^{-1})	36.3	35.7	36.1	0.27	N.S.
Milk fat (g kg^{-1})	46.0	45.8	45.7	0.63	N.S.
Milk solids (kg cow^{-1} d^{-1})	1.73^a	1.83^b	1.81^b	0.024	0.01
Cumulative milk solids (kg cow^{-1} $year^{-1}$)	460^a	496^b	493^b	10.9	0.05
Cumulative milk solids (kg ha^{-1} $year^{-1}$)	$1,261^a$	$1,361^b$	$1,353^b$	30.4	0.05

[1] s.e.m. = standard error of the mean; within rows, treatment values with differing lower case superscript differ significantly.

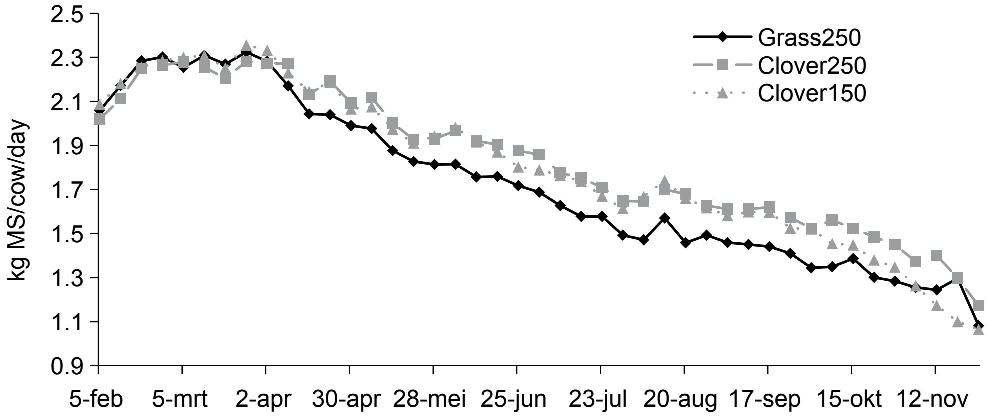

Figure 1. Average daily milk solids production (kg MS cow^{-1} day^{-1}) from a PRG only sward receiving 250 kg N ha^{-1} (Grass250), and PRG-clover swards receiving 250 kg N ha^{-1} (Clover250) or 150 kg N ha^{-1} (Clover150).

Conclusion

Milk solids production was greater on the PRG-clover treatments compared to the Grass250. Reducing N fertiliser application on the Clover150 treatment from May onwards resulted in greater sward clover content compared to Clover250. Herbage production was similar on all three treatments. The study shows that white clover can have a role in intensive pasture-based milk production systems and offers the potential to reduce fertiliser N application.

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Does white clover genotype affect the performance of grass-clover mixtures?

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Abstract

Compared to pure grass stands, grass-clover mixtures are usually higher yielding because of complementary resource use of the components. The number and identity of species in a mixture are important factors for the mixture's productivity. Little is known about the role of within-species genetic variation for the complementarity of the components. We established an experiment to investigate to what extent and how different genotypes of white clover (*Trifolium repens* L.) affect the mixture performance. Eight novel genotypes of white clover and one variety of *Lolium perenne* L. and *Cichorium intybus* L. each were grown as monocultures and in two- and three- species mixtures at two sites differing in soil fertility. All treatments were unfertilised. Above ground herbage was cut twice in the establishment year and four times in each of the two following years. At both sites, the binary mixture of white clover and *C. intybus* produced significantly higher DM yield than the other stands. Irrespective of the site effect, more than 80% of the mixtures showed transgressive overyielding. However, there was no significant interaction of white clover genotype × stand (i.e. monoculture or mixture) on the mixture performance; the white clover genotype that performed well in monoculture also did so in mixtures.

Keywords: mixed stand, monoculture, white clover, species complementarity

Introduction

The inclusion of white clover (*Trifolium repens* L.) in grass seed mixtures is a common practice as the herbage yield of mixtures usually exceeds that of the average of the respective monocultures, in particular when the fertiliser input is low. This effect is referred to as overyielding. Mixtures might produce even higher DM yields than the best monoculture which is called transgressive overyielding (Lüscher *et al.*, 2014; Ergon *et al.*, 2016). The extent to which overyielding or transgressive overyielding can occur depends on various factors, abiotic and biotic ones and their interactions (Prieto *et al.*, 2015). A considerable number of studies have shown that both the number of forage species and the number of plant functional groups in a mixture are positively related to the mixture yield. Much less attention has been paid to the effect of the within species genetic diversity and the resource availability on the mixture performance. As the major forage species of temperate grasslands show quite considerable genetic variation in their morphology and growing attributes it can be assumed that the complementarity of the mixture components varies accordingly. For the research presented here it was hypothesised that contrasting white clover genotypes would affect the performance of mixtures with non-legume species differently and that this would also depend on the resource availability at the site. In order to test this hypothesis, a field experiment on two contrasting sites was established with a range of different white clover genotypes grown as monocultures or mixtures with non-legume species.

Materials and methods

The experiment was undertaken at two sites on the experimental farm of Goettingen University, Germany, from 2014 - 2016. The two sites are noticeably different in terms of soil depth, fertility and temperature. The fertile site (51.29 N, 9.55 E) has a low elevation (157 m a.s.l.) with a Gleyic Fluvisol; the marginal site (51.34 N, 9.58 E) has an elevation of 342 m a.s.l., the soil is a Calcaric Leptosol. Eight novel genotypes of white clover from DSV (Deutsche Saatveredelung) which are different in plant height, leaf size, flowering time and yield potential, one variety of perennial ryegrass (*Lolium Perenne* L.) (ELP 060687) and one variety of chicory (*Cichorium Intybus* L.) (Puna II) were sown in four different stands: (1) monocultures (1000 seeds m^{-2}), (2) binary mixtures of white clover with either perennial ryegrass or (3) chicory (400:600) and in (4) three-species mixtures of white clover with perennial ryegrass and chicory (400:300:300). There was no application of any nitrogen (N) fertiliser. The experiment design was split plot with four replications. Each site consisted of 160 plots (5 × 3 m). All plots were cut twice during the establishment year (2014) and four times in the full years (2015 and 2016). Herbage was cut to a height of 5 cm with a combine harvester (Wintersteiger hd 1500). Sub-samples of fresh herbage were hand separated into the components (species) and dried to determine the component yields. The deviation value (difference between the mixture yield and the highest monoculture yield divided by the highest monoculture yield) was calculated to assess transgressive overyielding of the mixtures (Hector *et al*., 2002). The accumulated total DM yield of the mixtures over years and the deviation value were analysed by Linear Mixed-Effects Models (Lme). Model reduction and multiple comparisons testing (LSD) was undertaken using the software R.3.2.3 (R core team, 2015) and the packages 'nlme' (Pinheiro *et al*., 2017) and 'lsmeans' (Lenth, 2016).

Results and discussion

The accumulated total DM yield over three years was significantly affected by the stand × site interaction (Table 1). At both sites, the productivity of the binary mixture of white clover and chicory was significantly greater than that of the monocultures and the other mixtures (Table 1). On average, over all stands and sites, white clover genotypes yielded significantly different (Table 1); the values ranged from18.2 to 20.9 t ha^{-1}. There was no significant interaction of white clover genotype × stand (Table 1). A similar result was reported by Annicchiarico and Piano (1997). There is no consensus as to how strong transgressive overyielding may occur in grassland species mixtures (Lüscher *et al.*, 2014; Nyfeler *et al.*, 2009; Cardinale *et al.*, 2007). So, a key finding of our study was that 100 and 66% of the mixtures on the fertile and the marginal sites, respectively, showed transgressive overyielding, i.e. the mixtures were higher yielding than the best respective monoculture. The level of transgressive overyielding was dependent on the interaction of stand and site ($P < 0.001$). On average, over the three years and the white clover genotypes, the mixtures produced 4 to 17% greater biomass yields compared to the best monocultures.

Table 1. Cumulative DM yields over three years. Two sites differ in soil depth, fertility and temperature. Eight white clover genotypes cultivated as monocultures (WC), binary mixture with perennial ryegrass (WC/PR), binary mixture with chicory (WC/Ch) and three-species mixtures (WC/PR.Ch). The letters indicate differences among sites and stands.

Stand	Cumulative dry matter yield (t ha^{-1})		*P*-value			
	Marginal site	Fertile site	Genotype	Stand	Site	Stand × Site
WC	16.68^{eg}	15.17^{gf}	0.0050^{**}	$<0.001^{***}$	0.0759^{NS}	$<0.001^{***}$
WC/PR	16.07^{eg}	18.19^{cde}				
WC/Ch	20.31^{bc}	25.54^{a}				
WC/PR.Ch	18.36^{df}	23.53^{b}				

Conclusion

Our results showed that for the herbage production of white clover/non-legume species mixtures, the non-legume companion species was more important than the white clover genotype. By selecting the right companion species for white clover there seems to be a high potential to better exploit niche differentiation processes through an increased complementarity. Interestingly, in our study, regardless of site condition, more than 80% of the mixtures showed transgressive overyielding.

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Genotypic and environmental variance for white clover yield in a commercial breeding programme

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Abstract

Teagasc research demonstrates that incorporating white clover (*Trifolium repens* L.) into grazing swards contributes additional nitrogen (N) to grassland and increases forage quality leading to increased milk yields relative to grass-only swards, contributing to the economic and environmental sustainability of pastoral-based production systems. Two hundred and fifty eight full-sib white clover families were evaluated over three harvest years. Total yield of grass and clover was measured and the results were used to guide the development of new synthetic cultivars. In this paper we determine the genotypic and environmental variance and heritability of yield. The objective is to determine the potential of utilising these families to establish a training population to develop and assess genomic selection approaches for white clover breeding to improve agronomic performance. We found sufficient genotypic and phenotypic variation within this population and broad-sense heritability for forage yield was calculated as 0.76, indicating selection for forage yield will result in genetic gain.

Keywords: *Trifolium repens*, white clover, genomic selection, breeding, yield

Introduction

Incorporating white clover (*Trifolium repens* L.; WC) into perennial ryegrass (*Lolium perenne* L.; PRG) swards has the potential to reduce costs and increase animal performance (Hennessy, 2016). In particular, PRG-WC pastures receiving 150 kg ha^{-1} nitrogen (N) had similar herbage yields to PRG only pastures receiving 250 kg ha^{-1} N. Furthermore, annual milk solids (MS) production was increased by up to 31 kg milk solids cow^{-1} when average annual WC content in the sward was greater than 20%. Research has clearly shown the benefit for milk production of including WC in pastures for ruminant animals, as it is a high quality forage due to low levels of structural carbohydrates, higher digestible protein and a faster rate of passage through the rumen. However, there are challenges to growing WC in PRG swards including establishment and long-term persistence. There is also a risk of bloat, particularly when sward WC content increased above 60% (Hennessy, 2016). Previous research has shown that a WC content of 50% is a realistic target to increase milk yields considerably (Dillon, 2016). Teagasc have been breeding WC for almost 60 years at Oak Park and in the last five years have commercialised four new WC cultivars. A typical WC breeding programme can take up to 15 years from initial crossings to release of a new cultivar. There are opportunities to use DNA-based selection schemes to accelerate this process and increase genetic gain. This requires the establishment of a reference population from which phenotypes and genotypes are collected. Our objective for this study is to evaluate the potential to use an historical data set to establish a reference population for genomic selection (GS). In this paper we determine the genotypic, environmental variance and heritability for total WC and PRG forage yield from sward plots over three harvest years.

Materials and methods

Two hundred and fifty eight F1 WC families were evaluated for forage yield from 2010 to 2012 in a randomised block design with two replications. Plots were 6 × 1.5 m. In each plot 20 WC plants were transplanted into a PRG sward. The PRG cultivar Shandon (intermediate diploid) was used in all plots.

Each block was divided into 16 sub-blocks, each with three control WC cultivars (Chieftain, Galway and Avoca) and 15 F1 families. Plots were managed under a simulated grazing regime with plots cut seven to eight times per year using a Haldrup forage harvester and fresh weight measured at each cut (Table 1).

At each cut, yields within each sub-block were adjusted based on the control yields by calculating a sub-block adjustment value as follows:

$$a_i = X_i - \bar{\bar{x}}$$

where a_i is the adjustment value for the i^{th} sub-block, X_i is the mean of the checks within the i^{th} sub-block, and $\bar{\bar{x}}$ is the mean of all checks at that cut. Yields were then adjusted with the following formula:

$$\hat{Y}_{ij} = Y_{ij} - a_i$$

where a_i is the adjustment value for the i^{th} sub-block, Y_{ij} is the mean of the checks within the i^{th} sub-block. The phenotypic variance was calculated as follows:

$$\sigma_p^2 = \sigma_f^2 + \sigma_{fy}^2/y + \sigma_e^2/ry$$

where σ_f^2 is the genotypic variance for family, σ_{fy}^2 is the family by year variance, σ_e^2 is the residual variance, r is the number of replicates, and y is the number of harvest years. The phenotypic coefficient of variation (PCV) was calculated as:

$$PCV = (\sqrt{\sigma_p^2}/\bar{X})100$$

where σ_p^2 is the phenotypic variance, and $\bar{X}$ is the mean trait value. The genotypic coefficient of variation (GCV) was calculated as:

$$GCV = (\sqrt{\sigma_f^2}/\bar{X})100$$

where σ_f^2 is the family variance, and $\bar{X}$ is the mean trait value. Broad sense heritability was calculated as:

$$H^2 = \sigma_f^2/\sigma_p^2$$

where σ_f^2 is the family variance and σ_p^2 is the phenotypic variance.

Table 1. Dates on which forage yields were determined in the years 2010 - 2012.

Cut #	2010	2011	2012
1	19 - 26 April	10 - 11April	8 - 9 March
2	24 - 25 May	12 - 16 May	10 - 11 April
3	14 - 15 June	29 June - 1 July	8 - 9 May
4	21 - 23 July	3 - 7 August	27 - 29 June
5	17 - 18 August	13 - 14 September	8 - 9 August
6	7 - 8 October	19 - 21 October	20 - 21 September
7	-	25 November	30 October - 2 November

Results and discussion

The mean forage yield (WC + PRG fresh weight) varied between 2.53 and 20.14 t ha^{-1} depending on the year and cut (Table 2) and mean total forage yields varied between 40.64 and 61.29 t ha^{-1} over the three years.

The phenotypic variance (σ_p^2) was calculated to be 50.4%, the PCV was calculated to be 15.8% and the GCV was calculated to be 13.8%. The PCV and GCV were moderate and similar for forage yield, demonstrating that there is sufficient genotypic and phenotypic variation within this population to improve forage yield through selection. The broad-sense heritability (H^2) for forage yield was calculated to be 0.76 (76%). This is high and indicates that selection for forage yield (WC + PRG) within this population is likely to result in significant genetic gain. Seed from these families exists in storage and can be germinated for genotyping, and it has already been demonstrated that family mean genotypes and phenotypes can be used in developing GS models (Fè *et al.*, 2016).

Table 2. Total white clover and perennial ryegrass fresh yield (t ha^{-1}) from three harvest years variance σ^2).

Cut	Year 1				Year 2				Year 3			
	$\bar{x}$**	σ^2*	Min	Max	$\bar{x}$	σ^2	Min	Max	$\bar{x}$	σ^2	Min	Max
1	3.74	1.97	0.60	12.13	5.24	1.61	1.76	9.76	3.00	0.56	0.59	6.06
2	11.75	4.37	5.45	19.43	14.12	7.83	4.16	28.99	5.63	0.57	3.43	9.00
3	5.68	0.93	3.31	8.80	6.28	8.56	0	19.72	6.98	0.63	4.88	10.29
4	5.56	1.69	2.12	10.47	6.05	4.51	0	17.12	20.14	15.18	11.6	34.17
5	3.29	1.11	0.40	8.61	3.73	1.25	0.89	8.96	10.78	21.60	1.55	26.40
6	10.61	3.87	3.33	20.00	9.26	2.62	4.97	15.60	12.23	16.40	2.76	24.41
7	-	-	-	-	-	-	-	-	2.53	0.23	0.83	4.11
Ann***	40.64	45.62	21.56	65.69	44.70	96.03	11.18	93.13	61.29	166.25	32.93	100.24

*variance; **mean; ***annual yield.

Conclusion

In this paper we mined historical data from a WC population to determine phenotypic and genotypic variance for total forage yield. Broad-sense heritability for forage yield was high in the population and there was sufficient phenotypic variance. Combined with the availability of seed for genotyping, there is the opportunity to use this as a reference population to develop GS models.

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Comparison of relative agronomic performance of several fertiliser formulations in perennial ryegrass pasture

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Abstract

The relative agronomic performance of a number of nitrogen (N) fertiliser formulations, with and without gibberellic acid (GA_3), were examined in perennial ryegrass-based pasture during two growing seasons (2014 and 2016) in Northern Ireland. The aim was to monitor the effectiveness of the products in late winter/early spring in a mild, damp climate with no moisture deficit. Agronomic performance was assessed in terms of pasture dry matter (DM) yield and nitrogen response efficiency. The products were a mixture of commercially-available and newly developing granular, liquid and fine particle application (FPA) N fertilisers. The effectiveness of the liquid products was rapid in the initial period immediately following application, with significantly higher first cut DM yields. However, there was a significant drop in pasture growth of these plots at the second cut. Overall, there was no significant difference in performance between granular Urea, granular calcium ammonium nitrate (CAN), FPA products and treatments with and without Agrotain.

Keywords: perennial ryegrass, dry matter yield, nitrogen response, gibberellic acid

Introduction

Gibberellic acid (GA_3) is a form of plant hormone that has been applied to a range of plant types to stimulate growth or function (e.g. Matthew *et al.*, 2009; Parsons *et al.*, 2013). In pastures GA_3 has been shown to produce consistent initial increases in DM production following application. Gibberellins activate dormant enzyme systems and when applied to pasture they can stimulate out-of-season growth or accelerate growth through reserve mobilisation, leaf and stem elongation and promotion of flowering. In this way, GA_3 has potential to improve grass growth and performance particularly during late winter/early spring when moisture is generally non-limiting and growth can sometimes be slow (Matthew *et al.*, 2009; Parsons *et al.*, 2013). The objective of the present research was to assess the relative effectiveness of different forms, rates and timings of fertiliser N application, including a mixture of granular and liquid urea fertiliser with and without GA_3, in terms of pasture DM yield production and N use efficiency (kg DM kg^{-1} N applied). Experimental trials were conducted in spring (March – May) 2014 and spring 2016 on permanent, perennial ryegrass dominated grassland sites in Northern Ireland. Urea was the dominant N form used in this study as the trials were complimentary to similar trials carried out in New Zealand pasture, where urea is the preferred N source.

Materials and methods

In 2014, 96 experimental plots received one of 12 treatments (Table 1). Each 16 m^2 plot (apart from two control treatments (no N)), received 25 kg N ha^{-1} through one of the fertiliser forms. The GA_3 was applied at rates of 34 g ha^{-1} and 60 g ha^{-1} with both granular urea and with liquid urea. These were compared to granular urea (with no GA_3), granular CAN, urea + Agrotain, Fine particle application (FPA) urea and FPA urea + Agrotain (Table 1). Fine particle application refers to fertiliser ingredients finely ground to 100-200 microns (0.1-0.2 mm), with 30-40% water by weight. Treatments were applied in a randomised block design, with eight replication blocks. The grass on each plot was trimmed to a height of 5 cm in late March 2014, followed in early April by one application of each treatment. Grass Cut 1 took place three weeks after treatment application, using a Haldrup plot harvester, with a residual cut taking place three weeks later. All products were prepared on a per-plot basis and applied by hand over each plot area. Liquid treatments were dispensed into sterile 2 l plastic drinking water bottles and sprayed evenly across each plot using a perforated lid attachment. For the FPA treatments, a fine mist of water was sprayed over the designated plots, followed by the FPA treatment. This created a dew effect and allowed the fine particles to adhere to the grass leaves. The FPA products were applied low to the ground and there was very little wind on the day of application. No additional liquid was applied to the granular treatments.

In the 2016 study there were 72 experimental plots (each 16 m^2) and 9 experimental treatments (Table 1). Gibberellic acid was applied at two rates, 30 and 60 g active ingredient (a.i.) ha^{-1} along with 30 kg N ha^{-1}. In addition, in 2016 a liquid GA_3-K salt was applied at 30 g a.i. ha^{-1} with no N, along with a commercially available product ProGibb® at 8 g a.i. ha^{-1}. There were no FPA or Agrotain treatments in the 2016 trial. Products were applied twice in 2016 and there were two grass harvests along with a residual cut, with 3-4 weeks separating each cut. The second product application took place immediately following the first grass harvest. For both years an Analysis of Variance was carried out in Genstat Release 12 statistical software package. Fisher's Protected Least Significant Difference Test was performed to measure statistically significant differences (P < 0.01) in DM yield, N Uptake and N use efficiency between products.

Results and discussion

In 2014, plots receiving liquid urea + GA_3 at 34 g ha^{-1} had a mean yield of 2,180 kg DM ha^{-1} and an N response efficiency of 41.4 kg DM kg^{-1} N applied, three weeks following treatment application. Plots receiving liquid urea + GA_3 at 60 g ha^{-1} had a mean yield of 2,199 kg DM ha^{-1} and an N response efficiency of 42.1 kg DM kg^{-1} N applied. This was significantly (P < 0.01) greater than the mean DM yield of plots receiving granular urea (mean 1,718 kg DM ha^{-1}) and granular CAN (mean 1,664 kg DM ha^{-1}) three weeks following treatment application. However, at the residual harvest three weeks later (with no further product applied), DM yield and N response efficiency were significantly lower for the two liquid products (750 and 854 kg DM ha^{-1}, respectively), compared to all other treatments (1,217 and 1,242 kg DM ha^{-1}, respectively, for urea & CAN in granular form). Overall, there was no significant difference in DM yield or N uptake between plots receiving granular CAN, granular urea or FPA urea, with or without Agrotain. Despite the greater performance of the liquid urea + GA_3 products at Cut 1, the significantly

Table 1. Treatment descriptions for experimental trials conducted in 2014 and 2016.

Treatment	2014		Treatment	2016	
	Description	Application rate		Description	Application rate
1	Control	0 kg ha^{-1}	1	Control	0 kg ha^{-1}
2	Granular urea	25 kg N ha^{-1}	2	SustaiN	30 kg N ha^{-1}
3	Granular A + GA_3	25 kg N ha^{-1} + 34 g ha^{-1} GA_3	3	Product X (low)	30 kg N ha^{-1} + GA_3-k salt at 30 g a.i. ha^{-1}
4	Granular B + GA_3	25 kg N ha^{-1} + 60 g ha^{-1} GA_3	4	Product X (high)	30 kg N ha^{-1} + GA_3-k salt at 60 g a.i. ha^{-1}
5	Liquid urea	25 kg N ha^{-1}	5	Liquid SustaiN	30 kg N ha^{-1}
6	Liquid A	25 kg N ha^{-1} + 34 g ha^{-1} GA_3	6	Liquid SustaiN _ GA_3-K salt	30 kg N ha^{-1} + GA_3-k salt at 30 g a.i. ha^{-1}
7	Liquid B	25 kg N ha^{-1} + 60 g ha^{-1} GA_3	7	Liquid GA_3-K salt	30 g a.i. ha^{-1}
8	Control + Liquid surfactant	0 kg N ha^{-1}. Surfactant to match treatments 5, 6 & 7	8	ProGibb®	8 g a.i. ha^{-1}
9	Granular CAN	25 kg N ha^{-1}	9	Liquid SustaiN + ProGibb®	30 kg N ha^{-1} + ProGibb at 8 g a.i. ha^{-1}
10	Granular urea + Agrotain	25 kg N ha^{-1}			
11	FPA urea	25 kg N ha^{-1}			
12	FPA urea + Agrotain	25 kg N ha^{-1}			

reduced performance at the residual cut resulted in no significant difference between products in terms of total DM yield (Cut 1 + Cut 2).

In 2016, the liquid GA_3 salt at 30 g a.i. ha^{-1} and commercial product ProGibb® at 8 g a.i. ha^{-1}, applied alone with no N, recorded significantly lower ($P < 0.01$) grass DM yields at both Cut 1 and Cut 2 compared to the same treatments when applied along with N fertiliser (1218 kg DM ha^{-1} of ProGibb® with no N compared to 2270 kg DM ha^{-1} with N at Cut 2). In similar experimental field trials carried out in New Zealand (Matthew *et al*., 2009; Zaman *et al*., 2014; Bryant *et al*., 2016), GA_3 has been shown to provide a short-term increase in pasture growth, which generally lasts for one cut or grazing. When applied in combination with N, the pasture response persisted longer. The larger initial response at Cut 1 also appears to be more significant when both the GA_3 and the N fertiliser are in liquid form rather than granular.

Conclusion

The use of GA_3, in combination with a liquid urea-based N fertiliser provided a significant increase in pasture growth at Cut 1 in spring. However, there was a significant depression in growth following the initial response and, therefore, no overall net benefit of GA_3. The results of these trials were similar to recently published pasture trials carried out in New Zealand, all of which have been short-term trials. Longer-term studies looking at the residual effects of GA_3 on perennial ryegrass pasture growth are required.

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Amazing Grazing: substantial fresh grass intake in restricted grazing systems with high stocking rates

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Abstract

Due to larger herds on smaller grazing platforms, grazing has been decreasing in the Netherlands. It is a challenge for farmers to achieve high fresh grass intake in modern grazing systems with high livestock densities and high supplementation levels. Two grazing systems were studied during two consecutive years: strip grazing (SG) and compartmented continuous grazing (CCG), both with 7.5 cows ha^{-1} on the grazing platform. Cows had daily access to the paddock for 6-8 h during daytime. During the night, supplementary feed was provided (5 - 12 kg DM cow^{-1} day^{-1}; up to 8 kg DM day^{-1} of supplement, only maize silage was fed, above 8 kg DM a mixture of maize and grass silage was fed). Comprehensive data was collected on sward and animal performance focusing on grass intake. Both 2016 and 2017 showed an average grass intake ranging from 5.5 - 6.5 kg DM cow^{-1} day^{-1}. The systems showed no significant difference with respect to grass intake and milk production. Each year, on average 174% of the area of the CCG and 233% of the area of SG was mown for silage. The results of this experiment show that grass intake can be substantial (on average 1037 kg DM cow^{-1} during the grazing season) in restricted grazing systems with high stocking rates.

Keywords: Amazing Grazing, grazing systems, grass intake, grass production, strip grazing, compartmented continuous grazing

Introduction

Grazing is a low cost strategy (De Klein, 2001, McCall and Clark, 1999) and improves consumer perceptions of the dairy sector (Boogaard *et al.*, 2011). However, Dutch farmers are faced with new grazing challenges due to larger dairy herds on limited grazing areas. The Amazing Grazing project (Schils *et al.,* 2018) addresses the challenges that farmers face in developing grazing systems with high stocking rates. This study aims to evaluate fresh grass intake for two contrasting grazing systems with high stocking rates and high supplementation levels.

Material and methods

In 2016 and 2017, a grazing experiment was carried out at the 'Dairy Campus' research farm, Leeuwarden, the Netherlands on a marine clay soil. Two grazing systems in two replicates were compared: strip grazing (SG) and compartmented continuous grazing (CCG). Each grazing system was undertaken with 15 cows on 2.0 ha, equating to 7.5 cows ha^{-1}. Each day, cows in the SG system had access to a fixed area of two strips, which was a combination of a fresh new strip and the strip from the day before (total area 1,290 m^2). Grass not needed for grazing was mown to increase sward/grass quality and utilisation for the subsequent grazing. The CCG system had six compartments of 0.33 ha each. Each day, cows were moved to a new compartment and rotated on five compartments. The (variable) sixth compartment was cut for silage to increase sward utilisation. If the grass growth decreased, less fresh grass and more supplementary feed was offered. Cows only had access to grazing during day time, between morning and evening milking. At night, the cows were fed maize silage and concentrates. Based on the high stocking rate it was expected that neither of the systems would produce enough grass for full time grazing during the whole season, so supplementation was provided. All cows received a flat rate of 5.5 kg concentrates cow^{-1} day^{-1}. The amount of supplementary forage fed depended on the grass allowance and was fed after the evening milking; up to 8 kg DM day^{-1} only maize silage was fed, above 8 kg DM a mixture of maize and grass silage was fed. All supplementary forage and concentrate intakes were recorded individually. Fresh grass intake was calculated as a result of energy intake. The energy needed for milk production, maintenance and growth was calculated. The difference between the energy requirements and energy supplied from supplementary forage and concentrates should be filled in by grass with an analysed energy value. Animal weights were recorded daily. Milk production per cow, amount of supplementary feed and gross grass production were measured for both systems. The effects of the grazing system on grassland and animal performance were statistically analysed with ANOVA (Genstat 18th), using year and replicates as random factors.

Results and discussion

Table 1 presents the sward and animal performance of the two grazing systems as an average of 2016 and 2017. Grazing system had no significant effect on fresh grass intake. The overall average grass intake was 6.1 kg DM cow^{-1} day^{-1}, but varied from 9.1 kg DM cow^{-1} day^{-1}in spring (up to the end of May) to 5.9 kg DM cow^{-1} day^{-1} in mid-summer (up to the end of July) to 3.7 kg DM cow^{-1} day^{-1} in autumn. In 2016, the grazing season started on 18 April and finished at the end of October, whereas in 2017 the grazing started on 3 April and finished on 6 September due to high levels of rainfall.

With a daily grass intake of 6 kg DM cow^{-1} day^{-1}, one third of the total diet consisted of fresh grass which led to a total fresh grass intake of over 1 t DM during the season which is enough to be economically profitable (Van Den pol – Van Dasselaar *et al.,* 2010). Total gross DM production was significantly higher for SG compared to CCG mainly as a result of a higher mowing percentage combined with a higher mowing yield. The SG system had the highest grass production but requires more daily labour. The CCG system is relatively easy to manage from day to day but needs a good balance between grass growth and supplementary feeding. In both systems the grass allowance was fixed. Variations in grass growth were compensated by supplementary feed. Advisors and farmers are hesitant to adopt a system with fluctuating supplementary feeding as they expect a lower milk production. Although this experiment had no comparison with a fixed level of supplementary feed, milk production was not affected by the variation in grass supply and the accompanying variation in feed supplementation. Farmers with larger herds on smaller grazing platforms are indicating that grazing is difficult or even impossible. This experiment demonstrated that even with a stocking rate of 7.5 cows ha^{-1} both systems resulted in a fresh grass intake of 5 - 7 kg DM cow^{-1} day^{-1}. Total feed intake and animal performance were not significantly different in both grazing systems. These results are similar to Dale *et al.* (2008) who found no effect on milk production but a reduced DM yield with very short grazing rotations.

Table 1. Sward and animal performance of compartmented continuous grazing (CCG) and strip grazing (SG) (2016 and 2017).

Parameter	CCG	SG	s.e.d.[1]	*P*-value
Daily grass intake (kg DM cow^{-1})	6.2	6.0	0.0645	ns
Daily silage intake (kg DM cow^{-1})	7.4	7.2	0.1702	ns
Grass intake per cow season (kg DM cow^{-1})	1,040	1,034	19.9	ns
Fresh grass utilisation (kg DM ha^{-1})	7,801	7,758	149.2	ns
Mown for silage (kg DM ha^{-1})	2,362^{a}	3,817^{b}	373.1	0.03
Total gross production (kg DM ha^{-1})	10,163^{a}	11,575^{b}	512.5	0.05
Mowing percentage (% of area)	174	233	29.9	ns
Fat and protein corrected milk (kg cow^{-1} day^{-1})	28.0	27.4	0.232	ns
Body weight (kg)	607	602	8.63	ns

[1] s.e.d = standard error of the difference.

Conclusions

At a stocking rate of 7.5 cows ha^{-1}, a daily average fresh grass intake of 6.1 kg DM cow^{-1} day^{-1} was achievable. The grazing system, CCG or SG, had no effect on fresh grass intake and animal performance. Gross grass production was higher for SG than for CCG.

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Amazing Grazing: effect of cutting height and defoliation frequency on grass production and feeding value

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Abstract

In the Netherlands, different grazing systems are practised with the extremes of continuous grazing and strip grazing. To get more insight into the effect of these different stocking systems on grass production and feeding value under different post grazing residuals, a mowing experiment was conducted. In total, six treatments were compared; three defoliation frequencies (cut every two, three and four weeks) and two different stubble heights (3 and 5 cm). The total grass production of the system with a low stubble height and a high defoliation frequency was four to five tonnes dry matter (DM) ha^{-1} lower than the other systems as a result of a higher mowing frequency. The feeding value of the grass, measured as protein content and digestible organic matter (OM) percentage was significantly higher at a higher defoliation frequency but the difference could not compensate for the loss of DM production.

Keywords: Amazing Grazing, defoliation frequency, stubble height, grass production, digestible OM, perennial ryegrass

Introduction

In the Netherlands, there are a number of grazing systems practised with the extremes of continuous and strip grazing and intermediate systems like rotational grazing and compartment continuous grazing. The reasons farmers choose different systems include grass production and milk production, stability in feeding value and production, labour requirement, farm lay-out, automated milking systems and personal preference (Van den Pol-van Dasselaar *et al.*, 2016). In these different grazing systems the defoliation frequencies can vary from daily to four weeks. These systems commonly have high post grazing residuals (> 6 cm), while in New Zealand systems post grazing residuals are generally lower (3.5 cm; Lee *et al.*, 2008). In order to measure the effect of lower and higher post grazing residuals under different defoliation frequencies, a mowing experiment was conducted.

Materials and methods

A cutting experiment with four replicates was set up in spring 2015 on a permanent grassland with 80% perennial ryegrass (*Lolium perenne* L.*)* and 20% rough meadow grass (*Poa trivialis* L.*)*. The experiment was conducted on the Dairy Campus experimental farm in Friesland (the Netherlands) on a marine clay soil. It contained two factors: factor one was a fixed defoliation frequency: two, three and four week defoliation (Table 1) and factor two was stubble height; 3 and 5 cm. All treatments received the same amount of N artificial fertiliser ha^{-1} divided over six applications (80 kg N (23 - 3), 60 kg N (21 - 5 and 19 - 6), 55 kg N (15 - 7), 50 kg N (12 - 8) and 40 kg N (9 - 9), in total 345 kg N ha^{-1}). The swards were mown with a lawn mower (Etesia) because the standard mower could not harvest at a stubble height of 3 cm. A strip, 7 × 0.8 m was mown. All grass was collected, weighed and sampled (about 1 kg fresh material) for dry matter (DM) content and feeding value (crude protein, crude fibre content and digestible organic matter). The cumulative DM and N-yield from the individual harvests were calculated. At the start and the end of the experiment, the percentage of the surface covered with plants (sward density) was visually estimated. Data were analysed with the ANOVA test (Genstat 18th) with the replicates as random block factor.

Table 1. Defoliation schedule.

Week	0	1	2	3	4	5	6	7	8	9	10	11	12
2 Weeks	X		X		X		X		X		X		X
3 Weeks	X			X			X			X			X
4 Weeks	X				X				X				X

Results and discussion

The cumulative annual DM yield was significantly affected by defoliation frequency and stubble height (both P < 0.001, LSD = 687 resp. 561), and the interaction between both factors (P = 0.022, LSD = 971). The results are shown in Figure 1.

A lower defoliation frequency led to a significantly higher annual DM yield. In the three and four week defoliation frequency, stubble height influenced the annual DM yield positively. Despite the longer growing period, there was no significant difference in crude fibre content of the grass. The crude protein content was significantly lower (P < 0.001, LSD = 8) on the four week treatment. There was no significant effect of stubble height on the crude protein or crude fibre content. The digestible OM percentage was significantly higher (P = 0.015, LSD = 1.35) at a higher stubble height (80.5 at 3 cm stubble vs 82.3 at 5 cm stubble) but also significantly higher (P = 0.004, LSD = 1.65) for the two week defoliation treatment (83.2% at two weeks vs 80.4% at four weeks). There was no interaction for the effect of defoliation frequency and the stubble height on the feeding value parameters measured. Analysing the total N-yield, the treatments with the highest cumulative DM yield also had the highest N yield despite the lower crude protein content. The sward was visibly denser at the end of the season at the two weeks defoliation frequency. No difference in root numbers was observed. From experience, farmers often mention that higher stubble leads to a quicker regrowth. In this experiment, the treatments with a 3 cm stubble height and a defoliation frequency of three and four weeks had a higher DM yield than those with a 5 cm stubble height. This is similar to Davis (1977) who found that stubble density had a greater effect than stubble height. In this mowing experiment a two week defoliation schedule resulted in a 2 t DM ha^{-1} reduction compared with a three week defoliation schedule and about 5 t DM ha^{-1} reduction compared with a four

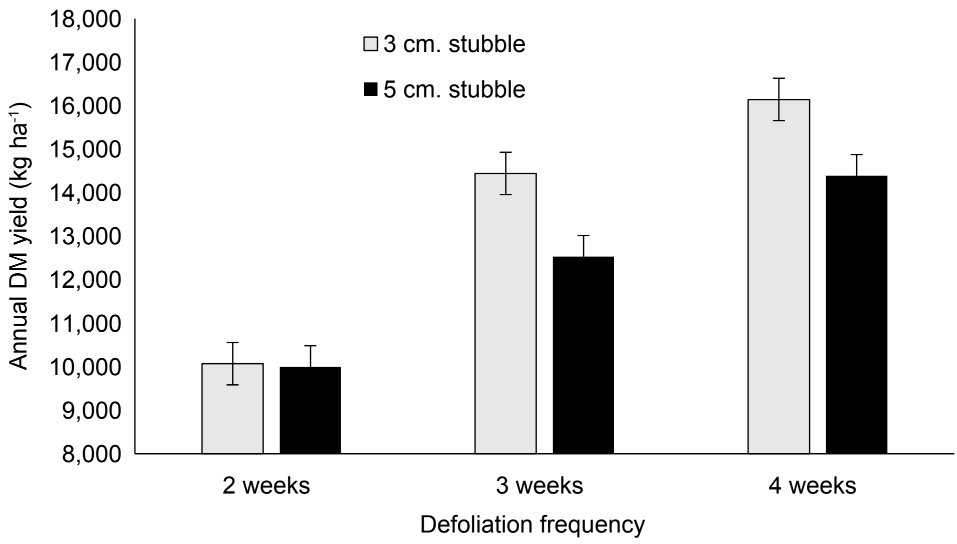

Figure 1. Cumulative annual DM yield at three defoliation frequencies and two stubble heights.

week mowing schedule. A higher defoliation frequency was also found at continuous grazing systems and this can be an indication for a lower gross yield production, also reported in the grazing experiment of the project Amazing Grazing (Holshof *et al.,* 2018). Due to the continuous grazing, a very dense sward will develop (also measured in the Amazing Grazing experiment) which could possibly compensate the lower vertical growth in this system. The cutting experiment was only one year duration and there was already a denser sward after the first season, however, one season was too short to measure this positive effect. Real time grazing may give a denser sward than just cutting. The higher protein content with the two week defoliation management could not compensate for the loss of DM yield, but the digestible OM percentage was slightly higher at a two week defoliation and a longer stubble. The short stubble could contain more dead leaf material due to the lawn mower used which allowed some pieces of very short material remain in the sward after mowing. In the next mowing, old material was picked up and affected the digestible OM.

Conclusion

A higher defoliation frequency will lead to a significantly lower total DM yield, with a higher protein content and a higher digestible OM. The higher protein level could not compensate for the lower DM yield, so the total N yield was also lower. Shorter stubble height led to a higher DM yield in combination with three or four weeks defoliation but resulted in a slightly lower digestible OM.

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The phenological development of three ryegrass clones and the influence of initial silage cut on regrowth under silage management

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Abstract

Due to its plasticity, perennial ryegrass (*Lolium perenne* L.) is suitable for both silage and grazing management in the diverse ruminant livestock systems of the UK and Ireland. Plant maturity influences the temporal change in quality of forage grasses when grown under different management systems, therefore, accurate identification of the growth stages of a grass sward is critical to many forage breeding and management decisions. The decision on harvest dates in breeder, official testing systems and on-farm is largely a visual estimation of the general phenological stage of the grass crop. This two-year study evaluates the effects of five harvest dates and three clonal swards of early, intermediate and late maturating perennial ryegrass on the primary and secondary re-growth under a 3-cut silage management. Delayed harvest increased the number of developmental stages recorded during primary growth but varied for the subsequent regrowth periods. Over years analysis showed that the mean developmental stage in the clones increased during primary growth. The initial cut date resulted in different response curves for four growth stage classes among the clones, only at silage cuts 1 and 2.

Keywords: ryegrass, clonal sward, phenology, silage, heading date, mean stage count

Introduction

Phenological development and its variation during primary and secondary growth have important effects on the yield and quality of forage grasses (Moore and Moser, 1995). In perennial ryegrass (*Lolium perenne* L.) genetic variation in heading date affects production and nutritional quality of cultivars when cut on the same date. Breeder, official testing systems and farmers make decisions on when to cut based on visual observation of the sward. Cutting too early or too late can change the balance between yield and quality. Numerous studies have quantified the developmental stages in a range of crops (Simon and Park, 1983; Ullmann *et al.*, 2016). There is a need to better understand the morphological development and changes in vegetative and reproductive tillers and their implications on growth and quality under silage management. The objective was to quantify the phenological variation and influence of initial silage cut (harvest cycle) date on subsequent regrowth using three clonal genotypes with different maturity dates.

Material and methods

A randomised split plot experiment with cloned plants of three intermediate diploid genotypes differing in mean heading date (differing by 16 days) was established in August 2013 at AFBI Loughgall. Treatments were assessed under a 3-cut silage management, with five 'harvesting cycles' (HC^{-14}, HC^{-7}, HC^{0}, HC^{+7}, HC^{+14}) at seven day intervals (28 day span), commencing with HC^{-14} on 8 May 2014 and 4 May 2015. Each first cut was given a re-growth period of six weeks to cut 2 (HC^{-14} cut date 18 June 2014 and 15 June 2015) and six further weeks to cut 3. A compound fertiliser containing 80 kg N ha^{-1} was applied after each harvest. A random sample of 70 tillers were cut 15 mm above ground level in each plot at each harvest cycle. The modified index of Moore *et al.* (1991) and Simon and Park (1983) was used to classify tillers into four major groups (vegetative, stem elongation, inflorescence development and heading). The number of Phenological growth Stages were Counted (PSC) and average growth stage (Mean Stage Count, MSC) were derived based on their numerical code (as shown in Table 1). Statistical analyses were performed using GENSTAT (Payne *et al.*, 2011).

Results and discussion

ANOVA revealed that harvest cycles differed significantly at silage cut (SC) 1 and 2 but not at SC 3. Clones were significant only at SC 2 with no interactions. A total of 17 individual growth stages (PSC) were recorded. Delaying harvests (HC^{-14} to HC^{+14}) increased PSC from 3.3 'leafy' stages to 12.2 'reproductive' stages. Whereas at SC2, PSC decreased from 9.5 to 3.6, but at SC 3 no trend was evident (Table 1). The MSC followed a similar trend to PSC in each silage treatment. Comparing the different maturing clones (E, I, L) it was found that maturity induced similar developmental changes as harvest cycle, in so much as it shifted the time frame but did not change the overall responses. The treatments show differences in the maturity and the shift from leaf to stem material within swards at SC 1 and SC 2 (Figure 1). As harvest is delayed (HC^{-14} to HC^{+14}), the early maturing clone transitions from a high leaf sward (LD + SE) to a sward predominantly with reproductive tissue (FD + EE), whereas the late maturing clone has less stem and more reproductive tillers by HC^{0}. The lag in development of reproductive stages between the two clones helps explain the yield differences with delayed cut (HC^{-14} 3.2, 1.7; HC^{0} 5.7, 4.9; HC^{+14} 8.3, 6.1 t DM ha^{-1} for early and late maturing clones, respectively). The effect of initial cut date has a major influence during the re-growth of SC 2. Harvesting two weeks (HC^{-14}) earlier than normal (HC^{0}) resulted in both clones being largely reproductive (FD+EE) at SC 2 indicating reproductive primordia were below the cut height at SC 1. The late maturing genotype was almost exclusively reproductive at SC2 compared with the early clone which had a higher proportion of leaf material. The influence at SC 1 was no longer evident at SC 3 (data not presented).

Table 1. The effects of harvest cycle and clone maturity on the number of phenological stages and mean stage count for silage cuts 1-3.[1]

	Silage cut 1		Silage cut 2		Silage cut 3	
	PSC	MSC	PSC	MSC	PSC	MSC
Harvest cycle						
HC^{-14}	3.3	2.03	9.5	3.49	5.0	2.27
HC^{-7}	5.0	2.53	8.9	3.42	3.9	2.22
HC^{0}	5.6	3.47	7.9	2.71	5.5	2.46
HC^{+7}	5.8	3.54	4.1	2.21	3.8	2.12
HC^{+14}	12.2	3.01	3.6	2.23	4.0	2.41
sem	0.70	0.02	1.09	0.09	0.48	0.05
Sign.	***	***	**	***	**	ns
Clone maturity						
Early	6.5	2.96	6.8	2.69	4.1	2.19
Intermediate	5.9	2.80	7.3	2.80	5.0	2.41
Late	6.8	2.99	6.3	2.94	4.3	2.33
sem	0.71	0.08	1.09	0.06	0.49	0.02
Sign.	*	*	ns	*	**	**

[1] PSC, phenological stage present; MSC, numerical mean stage count as per Simon and Park (1981); sem, standard error of the mean; ns, not significant; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

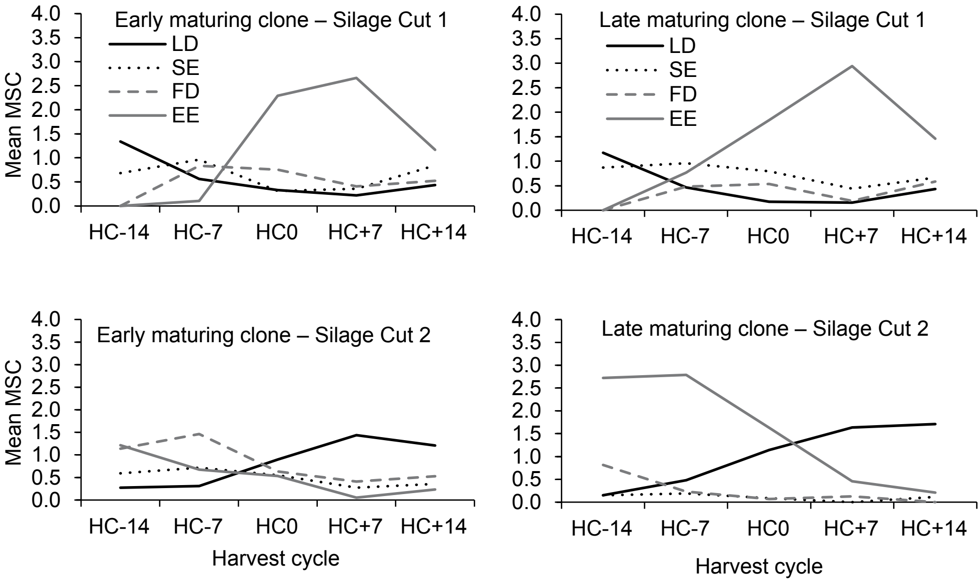

Figure 1. Early and late maturing clone mean stage count for the four growth stage classes (LD - leaf development; SE - stem elongation; FD - floral development; EE - ear emergence = heading) for silage cut 1 and 2.

Conclusion

The fact that different phenological stages were observed within a clone is evidence of non-genetic variation, most likely due to inter-tiller competition. The results of this study provide an understanding of tiller/sward dynamics and the underlying implications of timing of defoliation and plant maturity at the first silage cut altering the silage cut 2 re-growth.

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Comparison of total mixed ration and pasture-based diets on dairy cow milk and milk solids yield

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Abstract

Dairy cow diet is one of the main factors influencing milk production. It is generally accepted that cows fed a total mixed ration (TMR) diet have greater milk production than cows fed on pasture-based diets. Variation in pasture composition can also affect milk production. Recent research shows increased milk production from perennial rye grass (*Lolium perenne* L.; grass) – white clover (*Trifolium repens* L.; clover) swards compared to grass-only swards. The objective of this experiment was to examine the effect of diet on dairy cow milk and milk solids (MS) yield. The experiment had four treatments: (1) TMR (grass silage, maize silage, concentrate); (2) grazed grass only receiving 250 kg nitrogen (N) ha^{-1} (GR250); (3) grazed grass-clover receiving 150 kg N ha^{-1} (CL150); and (4) grazed grass-clover receiving 100 kg N ha^{-1} (CL100). There was a significant ($P < 0.05$) effect of treatment on milk yield, which was greater on the TMR treatment compared to the GR250, CL150 and CL100 treatments. Cumulative MS yield was significantly greater ($P < 0.05$) on TMR (640 kg MS cow^{-1}) compared to GR250 (482 kg MS cow^{-1}), CL150 (539 kg MS cow^{-1}) and CL100 (466 kg MS cow^{-1}), and was significantly less on CL100 compared to CL150.

Keywords: total mixed ration, pasture-based, milk solids yield, milk yield

Introduction

Variation in pasture quality in a grazing diet can have a significant effect on dairy cow milk production. Grazed pasture is the cheapest feed source available to Irish dairy farmers, with a relative cost ratio of grazed grass to concentrate of 1:2.4 (Finneran *et al.*, 2010). Increasing the proportion of grazed pasture in the dairy cow diet reduces the dependence on purchased feed, which is subject to substantial price volatility and farm labour compared to grazing alone (Dillon, 2011). Dairy cow diets in Ireland can comprise up to 80% grazed pasture and grass silage (Shalloo *et al.*, 2004). Ulyatt and Waghorn (1993) emphasised the major limitation of dairy cow production performance in pasture-based dairy systems is the low herbage dry matter intake (DMI), resulting in insufficient nutrient intake to exploit the genetic capability of the lactating animal to utilise nutrients for milk production. Typical total mixed ration (TMR) diets are more consistent in quality, have greater energy DMI and greater annual milk solids (MS) yield production compared to pasture-based systems, using a similar genetic merit cows in both systems (Kolver and Muller, 1998). There is increased interest in the use of white clover (*Trifolium repens* L.; clover) in pasture-based systems due to increased feed value and the potential to reduce nitrogen (N) fertiliser inputs (Egan *et al.*, 2018). The objective of this experiment was to examine the effect of diet (pasture or TMR) on dairy cow milk and MS yield.

Materials and methods

A full lactation farm systems experiment was undertaken at Teagasc, Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland from February to November 2017. In February, 68 spring calving dairy cows were selected from the Moorepark dairy herd, blocked according to breed (15 Friesians and 2 Jersey × Friesians per treatment), calving date (mean = 17 February ± 3 days), parity (2.53; 5 primiparous and 12 multiparous) and pre-experimental milk and MS yield, and randomly allocated to one of four treatments (n = 17). The four treatments were: total mixed ration (TMR), grass-only swards receiving 250 kg N ha^{-1} (GR250), grass-clover swards receiving 100 or 150 kg N ha^{-1} (CL100 and CL150, respectively). The GR250 swards were a 50:50 mix of perennial ryegrass (*Lolium* perenne L.) cultivars Astonenergy and Tyrella (sown at 27 kg ha^{-1}), and grass-clover swards were the same grass mixture, at the same sowing rate, plus a 50:50 mix of Chieftain and Crusader clover (sown at 5 kg ha^{-1}). The TMR treatment was housed indoors and fed using electronic controlled Roughage Intake Control system feed bins (Hokofarm Group B.V., Voorsterweg 28, 8316PT Marknesse, Netherlands). The diet, on a DM per cow basis, was grass silage (4.5 kg), maize silage (9 kg) and concentrates (8.5 kg) and was designed to support a peak milk yield of 34 litres based on cows similar to those used by McAuliffe *et al.* (2016). The TMR was fed daily at 08:30 h. The GR250, CL150 and CL100 treatments were stocked at 2.75 cows ha^{-1} in a closed farm system. Cows were allocated a daily pasture allowance of approximately 18 kg DM cow^{-1} to achieve a post-grazing sward height of 4 cm. Swards were rotationally grazed from February to November. Target pre-grazing herbage mass on all treatments was 1,400-1,600 kg DM ha^{-1}. Pre-grazing pasture mass was measured twice weekly in the area to be grazed next using an Etesia mower (Etesia UK Ltd., Warick, UK). Average sward clover content in CL150 and CL100 swards was measured twice weekly, prior to grazing, as described by Egan *et al.* (2017). Cows were milked twice daily at 07:30 and 15:30 h. Milk yields were recorded daily (Dairymaster, Causeway, Co. Kerry, Ireland) and fat and protein concentrations were measured weekly using a MilkoScan 7000 (Foss Ireland Ltd). Data were analysed in SAS using Proc Mixed with terms for treatment, time (week or rotation) and associated interactions. Fixed terms were treatment and week or rotation and random terms were cow and paddock.

Results and discussion

There was no significant treatment effect on pre-grazing herbage mass or post-grazing sward height (Table 1). This occurred due to the grazing management rules imposed which had the same target pre-grazing herbage mass and post-grazing sward height for each treatment. Pasture production was 14.6 t DM ha^{-1} on CL150, 13.4 t DM ha^{-1} on CL100 and 14.0 t DM ha^{-1} on GR250. Average annual sward clover content was similar (181 g kg^{-1} DM) for both grass-clover treatments. Peak sward clover content was achieved in September at 393 g kg^{-1} DM. Mean daily milk yield and MS yield were significantly greater ($P < 0.05$) on TMR compared to all other treatments, which did not differ from each other (Table 1), and were not significantly different amongst the pasture-based treatments. The TMR treatment had greater cumulative milk yield and MS yield compared to the pasture-based treatments. The CL150 cumulative MS yield was greater than CL100, which was similar to GR250 (Table 1). Similar cumulative MS yield on CL150 and GR250 suggests that in pasture-based systems, at a stocking rate of 2.74 cows^{-1},there is potential to reduce N fertiliser application from 250 to 150 kg N ha^{-1} when clover is introduced to the sward without reducing milk or MS yield. Reduced herbage quality may have resulted in the reduction in cumulative MS production on CL100 compared to GR250 and CL150; however, that data is not currently available.

Table 1. Herbage and milk production on total mixed ration (TMR) diet, grass-only swards receiving 250 kg N ha^{-1} (GR250) and grass-clover swards receiving 150 and 100 kg N ha^{-1} (CL150 and CL100, respectively).

	TMR	GR250	CL150	CL100	s.e.m.[2]	*P*-value
Pre-grazing pasture mass (kg DM ha^{-1})	-	1,588	1,530	1,470	145.3	ns[1]
Post-grazing sward height (cm)	-	4.01	4.11	4.03	0.101	ns
Daily milk yield (kg cow^{-1})	29.2^{a}	21.2^{b}	23.1^{b}	21.3^{b}	0.90	< 0.05
Daily milk solids yield (kg cow^{-1})	2.27^{a}	1.72^{b}	1.91^{b}	1.72^{b}	0.066	< 0.05
Cumulative milk yield (kg cow^{-1})	8,258^{a}	5,960^{b}	6,582^{b}	5,746^{b}	220.7	< 0.05
Cumulative milk solids yield (kg cow^{-1})	640^{a}	482^{bc}	539^{b}	466^{c}	21.1	< 0.05

[1] ns = not significant. Within rows, treatment values with differing lower case superscript differ significantly.

[2] s.e.m. = standard error of the mean.

Conclusion

The TMR treatment had greater daily milk, MS yield and cumulative milk yield compared to GR250, CL150 and CL100, which did not differ from each other. Cumulative MS yield from the TMR treatment was significantly greater than the other three treatments. The CL100 treatment had significantly less cumulative MS yield compared to the CL150 treatment. Sward clover content was similar when 100 and 150 kg N ha^{-1} were applied. In pasture-based systems, at a stocking rate of 2.74 $cows^{-1}$, there is potential to reduce N fertiliser application from 250 to 150 kg N ha^{-1} when clover is introduced to the sward without reducing milk or MS production.

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Effect of perennial ryegrass and white clover with perennial ryegrass forage on sward structure, *in vivo* dry matter digestibility and voluntary intake in individually housed sheep

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Abstract

Grass nutritive quality is a key driver of animal performance in grazing systems. The feeding value of mixed perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) swards (GC) is often greater than that of perennial ryegrass only swards (GO) in pasture-based ruminant production systems. Perennial ryegrass only and GC were evaluated for dry matter intake (DMI) and dry matter digestibility (DMD) using Texel wether sheep in spring, summer and autumn. Sward botanical characteristics were measured in GO and GC swards as was sward white clover content in the GC. There was no significant effect of treatment or season on DMI. Dry matter digestibility was significantly greater ($P < 0.001$) in spring (816 g kg^{-1} DM) compared to summer and autumn (759 and 745 g kg^{-1} DM, respectively). Grass leaf content was lowest in summer and sward dead content was lowest in spring. Sward white clover content was greatest in autumn (51.5%) compared to spring (19.7%) and summer (17.9%).

Keywords: perennial ryegrass, white clover, dry matter digestibility, dry matter intake

Introduction

Dry matter digestibility (DMI) has a major effect on the production performance of grazing ruminant animals (Roche *et al.,* 2008). White clover (*Trifolium repens* L., hereafter referred to as clover) has a faster rumen passage rate compared with perennial ryegrass (*Lolium perenne* L., hereafter referred to as PRG) as clover is more easily broken down in the rumen due to its lower fibre content (Beever *et al.*, 1986; Dewhurst *et al.*, 2003). As a result, ruminants grazing mixed grass and clover swards can potentially increase nutritive quality intake and production performance (Kemp *et al.*, 2010). Herbage mass and sward structure affect PRG digestibility (Beecher *et al.*, 2015). Maintaining a high PRG leaf percentage in the grazing sward is essential to maintain maximum nutritive quality in the sward (Beecher *et al.*, 2015). Clover percentages in the sward increase throughout the growing season, accounting for increases in nutritive intake and dry matter intake (DMI). High percentages of white clover inclusion generally reduce the amount of PRG stem and indigestible fibre in the grazing sward, often leading to higher nutritive quality pasture and increasing DMI. The objective of this experiment was to determine the effect of PRG only (GO) and PRG and clover (GC) swards on dry matter digestibility (DMD) and DMI, when offered fresh to individually housed sheep in spring, summer and autumn.

Materials and methods

An *in-vivo* 2 × 2 Latin square design experiment with two treatments GO and GC and two periods (P1 and P2) was undertaken using 12 Texel wether sheep at three time-points (seasons): spring (April), summer (June/July) and autumn (September). Each period was made up of a six day acclimatisation stage (to the diet and housing) and a six day measurement stage. The two periods were separated by an eight day rest period in spring and summer and a three day rest period in autumn. Sheep were offered feed for *ad libitum* consumption while individually housed in crates. The quantity of herbage offered to and refused by each sheep was weighed daily to calculate DMI. The amount of herbage offered daily was adjusted to 110% of the previous day's intake which allowed for a 10% refusal rate. Dry matter digestibility was calculated once faeces were collected and dried using the following equation:

$$DMD = \frac{DMI\ (kg) - quantity\ of\ faeces\ excreted\ (kg\ DM)}{DMI\ (kg)}$$

The pre-grazing herbage mass was measured twice during the measurement stage using a Gardena hand shears (Accu 60, Gardena International GmbH, Ulm, Germany) and a 0.25 m^2 quadrant (O'Donovan *et al*., 2002). Herbage was harvested fresh daily using an Etesia (Etesia UK Ltd., Warwick, UK) at 08:30 h. Pre- and post- cutting sward heights were measured daily using a plate meter (Jenquip, Fielding, New Zealand) after the morning cutting. Half was fed in the morning and the rest of the herbage was refrigerated at 4 °C until the evening feeding, at 15:30. A sample of approximately 200 g of the fresh herbage was dried at 120 °C for four hours, to estimate herbage DM content. Leaf, stem and dead proportion of both swards, and sward clover content in GC swards, was measured daily during the six day measurement period. Data were analysed using Proc Mixed in SAS with terms for treatment, season and the treatment × season interaction. Season and treatment were the fixed effects and the individual sheep were the random effect.

Results and discussion

There was no effect of treatment or season on pre-grazing herbage mass (spring 1,378 and 1,498 kg DM ha^{-1} on GO and GC, respectively; summer 1,735 and 1,790 kg DM ha^{-1} on GO and GC, respectively; autumn 1,700 and 1,553 kg DM ha^{-1} on GO and GC, respectively). Sward clover content was 19.6% in spring, 17.9% in summer and 51.5% in autumn on a DM basis. There was no significant effect of treatment or season on DMI (Table 1). Dry matter digestibility was not affected by treatment but was significantly ($P < 0.001$) affected by season (Table 1).

The DMD was significantly greater in spring than in summer and autumn (Table 1). There was a significant season × treatment effect on leaf proportion; leaf proportion in spring was greater on GO compared to GC swards. Sward leaf content was greatest in spring and sward dead content was least in spring (Table 1). There was a significant ($P < 0.05$) treatment × season effect on grass stem content; stem content of GO was greater than GC in autumn, and sward stem content was greater in spring and summer than in

Table 1. Herbage dry matter intake (DMI), dry matter digestibility (DMD), sward leaf, stem, dead and clover content in spring, summer and autumn on perennial ryegrass only (grass-only) and perennial ryegrass and white clover (grass-clover) swards.

	Treatment	DMI (kg day^{-1})	DMD (g kg^{-1})	Leaf (%)[1]	Stem (%)	Dead (%)	Clover (%)
Spring	Grass-only	1.99	814^a	77.5^a	17.3^a	6.2^a	-
	Grass-clover	2.0	817^a	71.3^{abc}	18.4^a	9.0^a	19.66^a
Summer	Grass-only	1.95	749^b	62.1^{bc}	25.9^b	11.6^b	-
	Grass-clover	1.90	769^b	64.4^{bc}	24.5^b	11.3^b	17.92^a
Autumn	Grass-only	1.86	740^b	72.0^{ab}	16.0^b	12.5^b	-
	Grass-clover	2.00	750^b	76.5^{ab}	10.7^c	12.9^b	51.54^b
	s.e.m[2].	0.077	9.1	2.84	1.08	1.71	4.141
	Treatment	ns[3]	ns	ns	< 0.01	ns	n/a[4]
	Season	ns	< 0.001	< 0.001	< 0.001	< 0.01	< 0.001
	Season × Treatment	ns	ns	< 0.05	< 0.05	ns	n/a

Letters within columns which are the same are not significantly different to each other.

[1] the sum of the leaf, stem and dead components does not always equal 100% due to rounding.

[2] s.e.m. = standard error of the mean.

[3] ns = not significant.

[4] n/a = not applicable.

autumn. These differences in sward leaf and dead contents contributed to the seasonal effects on DMD, due to the increase in stem proportion. Egan *et al.* (2017) Enriquez-Hidalgo *et al*. (2014) and Humphreys *et al*. (2009) found no differences in crude protein content or organic matter digestibility between GO and GC swards. Analyses of herbage nutritive quality parameters would provide information on the feed nutritive quality.

Conclusion

Clover inclusion did not have a significant effect on DMI or DMD in this experiment which is contrary to previously published research. Herbage quality analyses are required to determine if there were differences in herbage nutritive quality between sward types. Seasons had a significant effect on DMD. Leaf percentage was greater in spring compared to the other two seasons.

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Effect of management strategy on wilting of monocultures and mixture of red clover and perennial ryegrass

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Abstract

Limitations to the adoption of red clover (*Trifolium pratense* L.; RC) as a silage crop include its low dry matter (DM) at cutting and a perception that it loses moisture slowly during wilting. The dynamics of fresh weight (FW) loss over an approximately 48 h period was examined in a 3 × 3 factorial study over two harvests (H1 and H2) using three conditioned mown 'forages' i.e. red clover (RC), perennial ryegrass (*Lolium perenne* L.: PRG) and a PRG/RC mixture (210 and 580 g RC kg^{-1} DM at H1 and H2, respectively) and three management regimes, i.e. Undisturbed, occupying 75% of total area; Tedded over same area as undisturbed, and Tedded over whole area (swathe density reduced by 25%). Following mowing, swathes were reconstructed in mesh trays to measure FW loss (six replicates per treatment). At both harvests RC had a lower DM content than PRG, RC had a faster rate of wilting than PRG, and wilting of both forages was two to three times faster on the first than second day. Rate of wilting of the mixtures was generally the average of that of the two monocultures. Despite RC's faster rate of wilting than PRG, it still had a lower DM content after two days. Reducing tedded swathe density significantly enhanced wilting compared to the 'tedding only' treatment.

Keywords: red clover, perennial ryegrass, wilting, DM loss

Introduction

Red clover (*Trifolium pratense* L.; RC) has attributes that lend it to replacing imported protein feeds, including a high protein content and high intake characteristics (Frame *et al*., 1998). However, RC can be difficult to ensile due to its high buffering capacity, low C: N (carbon : nitrogen) ratio and higher moisture content, compared to grass treated under similar conditions. While conditioning after mowing has similar beneficial effects on wilting of perennial ryegrass (*Lolium perenne* L.; PRG) and RC (Fychan *et al*., 2017), this study was undertaken to investigate the effect of additional swathe management on wilting of these two forages in monoculture and mixture.

Materials and methods

Red clover cv. Merviot, PRG cv. Copeland and a mixture of the two were sown on 7 September 2016 in plots of 0.1 ha each. Red clover was sown at 8 and 15 kg ha^{-1} and PRG at 20 and 30 kg ha^{-1} in a mixture (RC-PRG) and as pure stands, respectively. After a clean off cut on 23 May 2017, 45 kg N ha^{-1} (as calcium ammonium nitrate) and 90 kg ha^{-1} K_2O (as muriate of potash) were applied to all plots, followed by 30 kg N ha^{-1} and 120 kg K_2O ha^{-1} after harvest 1 (H1) on 5 July 2017. A second harvest (H2) was taken on 25 September.

The experiment (3 × 3 factorial design) consisted of three sward types (described above), each subjected to three swathe management treatments, with each treatment replicated six times in a randomised block design. The three swathe management regimes were as follows: Undisturbed, occupying 75% of total area ('Undisturbed'); Herbage tedded by hand, over the same area as Undisturbed ('Tedded full density'); Herbage tedded by hand, with fresh weight (swathe density) within the tray reduced by 25% (Tedded 0.75% density), the latter treatment representing herbage tedded over the whole area. Loss of fresh weight (FW) during wilting was measured by reconstituting swathes in wire mesh (13 mm square mesh) trays

(0.5 × 0.5 m base × 0.3 m high), weighing the trays and measuring loss at 2 h intervals from approximately 10.00 h and 12.00 h (H1 and H2, respectively) until 18.00 h (Day 1), and again at 08.00 h (Night 1) and from approximately 8.00 to 18.00 h (Day 2), and again at 08.00 h (Night 2). Herbage at H1 and H2 was mown with a mower fitted with a steel flail conditioner, leaving a swathe covering 75% of the ground area. The amount of herbage to be used to reconstitute a swathe within a tray was determined before mowing by weighing herbage harvested with an Agria autoscythe in two 3 m long strips in each of the areas designated for harvesting (approximately 20 × 10 m) for each sward type. Immediately prior to setting up the trays, herbage was sampled for DM content by taking samples within each plot for each of the six replicates and dried at 60 °C. All herbage within the trays was dried at 60 °C at the end of the wilting period. Differences between treatment means for consecutive periods during each day were analysed by repeated measurements analysis, and for nights by analysis of variance (sward type, sward management and interaction as factors, with residual as error variance; GenStat for Windows, 16th Edition).

Results and discussion

Interactions between swathe management regimes and forage type were not significant and so only the main effects are presented. Dry matter yields of RC, RC-PRG and PRG at H1 were 5.62, 4.73 and 3.57 t ha^{-1}, respectively, and at H2 2.84, 4.09 and 2.00 t ha^{-1}, respectively. Other than Day1 of H1, conditions were more conducive for drying at H1 than H2 (Table 1).

Red clover had a lower DM content than PRG following mowing at both harvests. Oven DM contents for RC, RC-PRG and PRG were 95, 102 and 117 ± 5.0 g DM kg^{-1} FW at the beginning of H1 and 161, 145 and 266 ± 12.0 g DM kg^{-1} FW at the beginning of H2. The rate of FW change of forage types over the consecutive wilting periods are presented in Table 2. Fresh weight loss of RC-PRG during wilting was generally similar to PRG during H1 and RC during H2. In three of the four days (to 18.00 h) over the two harvests, RC lost FW significantly faster than PRG and rate of loss was higher in Day 1 of H2 than H1, despite drying conditions suggesting the contrary. Oven DM at end of wilting for RC, RC-PRG and PRG at H1 were 174, 191 and 205 g DM kg^{-1} FW (s.e.d. 6.40, $P < 0.001$), respectively, and at H2 were 236, 213 and 322 g DM kg^{-1} FW (s.e.d. $P < 0.001$), respectively. Weight of DM of all forages in trays was reduced during wilting.

Fresh weight reduction was greater in the first than second day of wilting at both harvests by a factor of two to three (Figure 1). Rate of FW loss from all forage types was significantly and consistently higher for tedded than undisturbed herbage at the lower density, agreeing with the findings of Wright *et al.* (1997) for PRG, while loss from the tedded forage at full density was only occasionally greater than for the undisturbed treatment.

Table 1. Mean air temperature (Temp, °C) and evapotranspiration (ET, mm h^{-1}) for day and night periods during Harvests 1 (H1) and 2 (H2).

	Day 1		Night 1		Day 2		Night 2	
	Temp	ET	Temp	ET	Temp	ET	Temp	ET
H1	16.2	0.188	14.2	0.021	18.2	0.160	15.8	0.031
H2	16.1	0.228	11.9	0.004	13.7	0.078	14.1	0.023

Conclusion

Reducing swathe density on conditioned RC herbage enhanced wilting more so than disturbing the swathe by tedding alone. Swathe management, however, had only a minor beneficial effect on wilting of RC relative to PRG.

Table 2. Rate of fresh weight (FW) change (positive = reduction), meaned across swathe treatments, relative to initial FW (g $kg^{-1}h^{-1}$) during wilting at Harvests 1 and 2 for red clover (RC), perennial ryegrass (PRG) and RC-PRG mixture.

Harvest	Periods		Forage			s.e.d.	*P*
			RC	RC-PRG	PRG		
1	Day 1	10.00 - 18.00	39.6^a	38.3^b	38.5^{ab}	0.61	0.042
		18.00 - 8.00	1.5	1.5	1.5	0.06	NS
	Day 2	8.00 - 18.00	16.9^a	16.0^b	15.1^c	0.27	< 0.001
		18.00 - 8.00	1.2	1.1	0.9	0.13	NS
2	Day 1	12.00 - 18.00	56.1^b	59.3^a	55.3^b	1.32	0.007
		18.00 - 8.00	-5.3^b	-5.1^b	-5.8^a	0.13	< 0.001
	Day 2	8.00 - 18.00	21.0^a	20.7^a	18.3^b	0.66	< 0.001
		18.00 - 8.00	-1.6	-0.6	-0.3	0.22	NS

[a-c] Means with different superscripts within rows differ ($P < 0.05$); † $P < 0.1$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS, not significant.

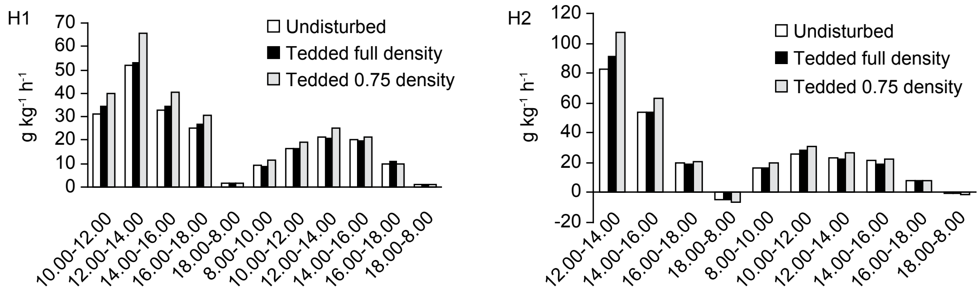

Figure 1. Rate of fresh weight (FW) loss (per hour) per kg initial FW during wilting at harvests H1 and H2 for each swathe management treatment. (Standard error of differences and significance (*P*) for Day 1, Night 1, Day 2 and Night 2 in H1 are 1.67 (< 0.001), 0.06 (NS), 1.20 (< 0.001) and 0.14 (NS), respectively, and in H2 3.39 (< 0.001), 0.13 (< 0.001), 1.83 (0.078) and 0.22 (< 0.001)).

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Grass growth models for estimating digestibility and dry matter yield of forage grasses in Finland

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Abstract

Grass growth models that describe the development of grass digestibility (D-value, g kg^{-1} DM) at the first silage cut are widely used in Finland for optimal timing of harvests, due to the rapid decline in D-value prior to the optimal harvest stage. However, the models need to be improved in order to provide estimates of D-value and DM yield for all harvests (first, second and third cuts) taken during the growing season. Our aim is to publish statistical growth models that predict digestibility and DM yield (kg DM ha^{-1}) in all three cuts for Timothy (*Phleum pratense* L.*)* and Meadow fescue (*Festuca pratensis* Huds.) swards. The models are based on data collected around Finland from 1996 to 2016. The updated models are regression or random regression models where the explanatory variables are the temperature sum or growing time. Other parameters, such as geographical location and the date of the previous cut, are also used.

Keywords: digestibility, dry matter yield, grass, growth model, temperature sum

Introduction

The long day length and abundance of light during the development of grass in spring in Finland leads to a fast growth rate and rapid decline in digestibility (D-value, g kg^{-1} DM). A calculator based on a grass growth model was released on the Internet almost 20 years ago ('Artturi'; Rinne *et al.*, 2001) to help farmers optimise the D-value of the first cut. Since its release, the model has been improved and models for the D-value of the second cut and for the DM yield for each cut have been developed (Rinne *et al.*, 2010; Rinne, 2012; Hyrkäs *et al.*, 2016). Our aim was to collect and assess existing models to choose the best and to create a combination model for the whole growing season and publish it on the Internet.

Materials and methods

The models for the first cut are based on data collected from 61 sites around Finland from 1996 to 2006. The data consist of 109 time series, including a total of 462 observations. The data for the second cut was collected from 1998 to 2011 and it includes 30 sites, 100 DM yield time series (453 observations) and 103 D-value time series (466 observations). The majority of the data for the first and second cuts were collected from second-year Timothy (*Phleum pratense* L.; T) and Meadow fescue (*Festuca pratensis* Huds.; MF) mixed swards by sampling 1 m^2 areas. The data for the third cut includes the official variety trial data gathered around Finland and cutting time experiment data collected from central and northern Finland. In total, the third cut data consists of 135 DM yield observations and 113 D-value observations from 2007 to 2016. Variation between cultivars was reduced by calculating the means of different cultivars with the same location and cutting date. The data for the third cut was collected from experimental plots (size 12 m^2) from pure or mixed T and MF swards. The pepsin-cellulase method (Rinne *et al.*, 2010) was used to measure D-values of the first cut. For the second and third cuts, 59 and 95% of the D-value observations were measured using near infra-red spectrometry. The rest of the observations were measured with the pepsin-cellulase method. Weather parameters were based on temperature and precipitation data from the Finnish Meteorological Institute. The effective temperature sum (°C d) for growth varied between 49 - 561, 171 – 1,100 and 249 - 696 and growing time between 9 - 81, 17 - 105 and 26 - 77 days in the first, second and third cut, respectively.

The aim was to keep the models as simple as possible and basic information needed to run the models easily accessible (Table 1). A Function resembling Gompertz-curve (Thornley *et al.*, 2007) was used as a starting point for developing models for D-value in the first cut (M1) and (M2). Models for the DM yield of the first cut (M3) and D-value (M4) and DM yield (M5) of the second cut were random regression models. Models for the D-value (M6) and the DM yield (M7) of the third cut were regression models. Due to the use of longitudinal observations, random effect models were used for the first and second cuts, except for M1, which estimated parameters by taking 5,000 bootstrap samples from the data, fitting 5000 models and then calculating a mean from the parameter estimates. All models were developed by adding effects one by one to the model. The effect was included if it was statistically significant ($P < 0.05$). The best models were selected using Akaike's information criterion (AIC), residual errors, the coefficients of determination, graphs or biological rationality. The M1 was fitted by the *Nlin* procedure, M2 by the Nlmixed procedure, M3-M5 by the Mixed procedure and M6 - M7 by the Reg procedure of the SAS software suite. Since the models are based on plot experiments or small (1 m^2) yield samples, DM yield models are scaled to the field scale by multiplying by a coefficient of 0.7, which is based on grass DM yield differences between Luke's experimental farm and official variety trials at Luke Maaninka (years 1995 – 2007; used for example in Nousiainen *et al.,* 2007).

Results and discussion

The models for the first cut (M1 – M3), second cut (M4 – M5) and third cut (M6 – M7) are presented below with root-mean-square errors (RMSE) and relative prediction errors (RPE). The variables used in the models are explained in Table 1. Model 1 is the latest version of the 'Artturi' model. Two models for the D-value of the first cut are published, since both are currently used. In the case of other models, only one model has been selected for each cut from among different models.

(M1) $\text{D-value}_{cut1a} = 776.27 - 216.21 \times \exp(-\exp(-0.0082 \times (TS1 - 327.75) - 0.0165 \times (x - 3204974) \times (y - 6666700) \times 10^{-10} - 0.0276 \times (x - 3204974) \times 10^{-5} + 0.0261 \times (y - 6666700) \times 10^{-5}))$, RMSE = 21.6, RPE = 0.024

(M2) $\text{D-value}_{cut1b} = 769.5 - \exp(5.61 \times (1 - \exp(-0.07 \times (TS_1 \times 10^{-1} + 0.016 \times PreGS_{28} - 7.58))))$, RMSE = 21.8, RPE = 0.024

(M3) $\text{DM yield}_{cut1} = 0.7 \times 1000 \times (-1.20 + 0.021 \times TS_1)$, RMSE = 1,207, RPE = 0.29

(M4) $\text{D-value}_{cut2} = 779.1 - 0.3178 \times TS_2 + 0.0002 \times TS_2^2$, RMSE = 34.5, RPE = 0.041

(M5) $\text{DM yield}_{cut2} = 0.7 \times (-1{,}511 - 2.621 \times TS_1 + 164.0 \times GT_2 - 0.786 \times GT_2^2)$, RMSE = 1,301, RPE = 0.400

(M6) $\text{D-value}_{cut3} = 723.70 + 0.6127 \times T_2 - 0.1055 \times TS_3 - 7.8189 \times P_3$, RMSE = 16.8, RPE = 0.017

(M7) $\text{DM yield}_{cut3} = 0.7 \times (4436.71 - 57.858 \times T_2 + 793.62 \times \ln(GT_3))$, RMSE = 501, RPE = 0.161

Table 1. Variables used in the models.

x		X-coordinate of location in Finnish Uniform Coordinate System (YKJ)
y		Y-coordinate of location in Finnish Uniform Coordinate System (YKJ)
TS_z, z = 1,2,3	°C d	Effective temperature sum (base temperature 5 °C) during yield development z
GT_z, z = 1,2,3	d	Growing time of yield z
T_2	d	Number of days from 1 May to the second cut
P_3	mm	Daily mean precipitation during development of the third yield
$PreGS_{28}$	°C	Sum of the mean temperatures of the 28 days before the beginning of the growing season

Model functions were solved using data from a single field experiment (Table 2) to demonstrate how the functions respond to given input data. The yield predictions based on observed input values for the first, second and third cut were 4,168 (M3), 1,737 (M5) and 1,996 kg DM ha^{-1} (M7), respectively. For D-value the predictions for the first cut were 675 (M1) and 647 g kg^{-1} (M2) and for the second and third cut 680 (M4) and 706 (M6) g kg^{-1} DM, respectively. The D-value for total yield was 684 g kg^{-1} if (M1) or 669 g kg^{-1} if (M2) is used for the first cut. The estimates of DM yield and D-value seem quite realistic, although the DM yield estimates of the second cut are slightly lower than those usually observed on experimental plots. Model 2 clearly underestimates the D-value, but it has been found to predict D-value better than M1 in some situations, e.g. when the growing season starts late. It must be taken into account that DM yield estimates based only on weather conditions are not very accurate, because in reality, DM yield is affected by the cultivar, the density and age of the sward, water management, soil fertility and fertilisation. Calculators based on the models are available on the Internet (www.karpe.fi, in Finnish).

Table 2. Input data for the example models for Maaninka, Kuopio, Finland, year 2016.

Latitude	63°14’ N	Second cut date	19 Jul 2016
Longitude	27°31’ E	Time of second cut (days from first May, T_2)	79 d
Y	7003414	Effective temperature sum (TS_2)	425.6 °C d
X	3515304	Growing time (GT_2)	36 d
Beginning of the growing season	26 Apr 2016	Third cut date	31 Aug 2016
$PreGS_{28}$	78.1 °C	Effective temperature sum (TS_3)	477.1 °C d
First cut date	13 Jun 2016	Daily mean precipitation (P_3)	2.07 mm
Effective temperature sum (TS_1)	340.7 °C d	Growing time (GT_3)	43 d
Growing time (GT_1)	48 d		

Conclusion

The new combined model improves methods of estimating how grass growth and the decline of digestibility are affected by the temperature and growing time in Finnish climate conditions. However, the reliability of the models estimates needs to be assessed case by case, due to the high variation in DM yields and D-values caused by non-climatic factors.

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Longer growing season with warmer autumn at northern latitudes – can farmers take an extra cut?

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Abstract

Rising temperatures during spring and autumn have led to significantly longer growing seasons in Norway during the last 30 years. Warmer autumns could give more regrowth of grass after the traditional last cut before winter and the management of this regrowth may affect the overwintering capability of swards. In this study, we examine how different harvest times in autumn affect yields of leys the following year. We established field experiments with three replicates in leys dominated by timothy (*Phleum pratense* L.) at four climatically contrasting sites in Norway in 2015. In 2016, we used a two-cut system for silage production in the two lowland locations in western and mid Norway, while in the mountain and northern site a two-cut system with early or normal second cut was used. After the two main cuts, one extra cut was made during autumn either four, six, eight or ten weeks after the main cuts. In the mountain and northern sites, cuts during late autumn (after mid-September) caused significantly lower yields in the first cut in 2017.

Keywords: timothy, climate change, growing season length, warm autumns, production

Introduction

The length of the thermal growing season has increased by one to two weeks during the last 30 years in Norway (Hanssen-Bauer *et al.*, 2015). Both spring and autumn temperatures show significantly increasing trends. This gives potential for higher yields or more cuts in grassland production. Two-cut systems are common in silage production over a wide range of climatic conditions in Norway. With earlier springs and longer growing seasons, farmers may harvest the second cut earlier than traditionally. The extra autumn regrowth after the second cut may give the potential for a third cut. However, harvesting in autumn can be demanding due to unfavourable weather conditions and increased risk of winter damage (Rapacz *et al.*, 2014). Abundant regrowth on the other hand could hamper next year's spring production due to an excess of dead plant material. In this study, we measured the amount of autumn regrowth in fields at contrasting locations and studied how either leaving the regrowth or cutting it at different times affected total yields and next year's production.

Materials and methods

We established a randomised block field experiment with three replicates in 2015 at four sites with contrasting winter and summer climates in Norway, two lowland sites - Fureneset (61°N, 10 m.a.s.l. - west coast) and Kvithamar (63°N, 28 m.a.s.l. - mid-Norway), a mountain site - Løken (61°N, 530 m.a.s.l. and a northern site - Holt (69°N 14 m.a.s.l.). The experiments were established with a seed mixture of 70% timothy (*Phleum pratense* L.), 20% meadow fescue (*Festuca pratensis* Huds.) and 10% red clover (*Trifolium pratense* L.). Red clover was omitted at the northern site. In 2016 and 2017, the lowland sites were fertilised with a total of 220 kg nitrogen (N) ha^{-1}, with 120 kg N ha^{-1} applied in spring and the rest after first cut. The northern site received a total of 160 kg N ha^{-1}, while the mountain site received 170 kg N ha^{-1} (both received approximately 100 kg N ha^{-1} in spring). All plots (10.5 m^2) were cut twice during the growing season, with the first cut at early heading of timothy (mid-June at the lowland sites and at the end of June and the beginning of July at the mountain and northern sites). The second cut was taken in mid-August at the lowland sites and these fields were subjected to five different cutting regimes for the autumn growth: no cut (treatment 1), or cut four, six, eight or ten (treatments 2 to 5) weeks after the second cut (Table 1). The second cut at the mountain and northern sites was made either 'early' (*c.* 10 August) or 'normal' (*c.* 28 August). The autumn regrowth in treatments with an early second harvest were either not cut or cut four, six or eight weeks after the second cut (treatments 6 to 9) (Table 2). In treatments with a 'normal' second harvest, the autumn regrowth was not cut, or cut after six weeks (treatments 10 and 11). Plots were harvested (Haldrup F-55, 2010) and weighed and DM yields were determined for all harvests after drying subsamples at 60 °C for 48 h. Effects of autumn cutting treatments on DM yields within each site were analysed using analyses of variance with the GLM procedure (SAS Institute Inc., 2012).

Table 1. Yields (tons ha^{-1}) per cut in 2016 and effects of cutting regrowth in 2016 autumn on first cut yields in 2017 for the lowland (Kvithamar and Fureneset) sites. S.E. - standard errors.[1]

Site	Treatm. No.	Autumn regrowth, date cut in 2016	2016					S.E.	2017	
			1st and 2nd cut	S.E.	Autumn regrowth	S.E.	Total		1st cut	S.E.
Kvithamar	1	Not cut	12.92^{a}	0.37	-	-	12.92^{a}	0.37	4.51^{a}	0.23
	2	07 Sep	11.76^{a}	0.72	0.60^{b}	0.04	12.36^{a}	0.69	4.29^{a}	0.15
	3	22 Sep	12.33^{a}	0.45	0.86^{ab}	0.04	13.19^{a}	0.44	3.97^{a}	0.12
	4	04 Oct	12.42^{a}	0.41	0.96^{ab}	0.07	13.38^{a}	0.45	3.91^{a}	0.06
	5	19 Oct	11.75^{a}	0.37	1.21^{a}	0.14	12.96^{a}	0.49	4.29^{a}	0.15
Fureneset	1	Not cut	11.30^{a}	0.18	-	-	11.30^{b}	0.18	9.04^{a}	0.28
	2	07 Sep	12.30^{a}	0.61	0.73^{b}	0.07	13.03^{a}	0.68	9.22^{a}	0.55
	3	22 Sep	11.24^{a}	0.45	1.33^{a}	0.13	12.57^{ab}	0.57	8.87^{a}	0.56
	4	04 Oct	11.19^{a}	0.39	1.58^{a}	0.15	12.77^{a}	0.53	8.78^{a}	0.45
	5	19 Oct	10.93^{a}	0.41	1.60^{a}	0.07	12.53^{ab}	0.48	8.73^{a}	0.56

[1] Numbers followed by the same superscript letter within column and sites are not significantly different according to Tukey's test ($P < 0.05$).

Table 2. Yields (tons ha^{-1}) per cut in 2016 and effects of cutting regrowth in 2016 autumn on first cut yields in 2017 for the mountainous (Løken) and northern (Holt) sites. Second cut in treatments 1 - 4 were taken in mid-August, while in treatments 5 - 6 it were taken in late August.[1]

Site	Treatm. No.	Autumn regrowth, date cut in 2016	2016					S.E.	2017	
			1st and 2nd cut	S.E.	Autumn regrowth	S.E.	Total		1st cut	S.E.
Løken	6	Not cut	10.95^{a}	0.53	-	-	10.95^{a}	0.53	7.33^{ab}	0.17
	7	14 Sep	11.20^{a}	0.50	0.45^{a}	0.02	11.66^{a}	0.53	6.83^{b}	0.07
	8	26 Sep	10.90^{a}	0.51	0.61^{a}	0.21	11.52^{a}	0.70	6.73^{b}	0.40
	9	10 Oct	11.58^{a}	0.40	0.71^{a}	0.14	12.29^{a}	0.41	6.73^{b}	0.21
	10	Not cut	12.13^{a}	1.12	-	-	12.13^{a}	1.12	8.14^{a}	0.47
	11	10 Oct	11.91^{a}	0.17	0.44^{a}	0.07	12.34^{a}	0.25	7.56^{ab}	0.10
Holt	6	Not cut	8.85^{a}	0.53	-	-	8.85^{a}	0.20	3.73^{a}	0.29
	7	10 Sep	7.85^{a}	0.39	0.24^{a}	0.08	8.09^{a}	0.39	3.12^{ab}	0.10
	8	23 Sep	8.29^{a}	0.58	0.36^{a}	0.08	8.65^{a}	0.20	2.98^{b}	0.05
	9	10 Oct	8.60^{a}	0.65	0.15^{a}	0.04	8.76^{a}	0.21	3.13^{ab}	0.02
	10	Not cut	9.25^{a}	0.25	-	-	9.25^{a}	0.26	3.20^{ab}	0.14
	11	10 Oct	9.01^{a}	0.44	0.05^{a}	0.02	9.05^{a}	0.32	3.06^{b}	0.16

[1] Numbers followed by the same superscript letter within columns and sites are not significantly different according to Tukey's test ($P < 0.05$).

Results and discussion

The DM yields from first and second cut were high at the lowland sites in 2016. Autumn DM yields were relatively small even after ten weeks of regrowth after the second cut. There were no large differences in temperature sums between the two periods, 593 and 576 growing degree-days, (GDD, base 5 °C) between first and second cuts at Kvithamar and Fureneset, respectively, compared to 416 and 517 GDD from the second cut until 19 October. In the same periods, global radiation was 1,054 and 771 mega joule (MJ) m^{-2} compared to 555 and 469 MJ m^{-2} in Kvithamar and Fureneset, respectively. The autumn cutting treatments did not affect DM yields the following year.

The yields in the mountainous site (Løken) were quite high but low at the northern site (Holt), especially in 2017. Autumn regrowth was very low also at these sites, even if the average September temperatures were higher than the average for 1961 - 1990. Temperatures during summer and autumn periods could not alone explain the drastically lower yields. Temperature sums were 422 and 295 GDD from the first to the second cut in mid-August, and 322 and 273 from mid-August to 10 October for Løken and Holt, respectively. Global radiation were 847 (Løken) and 524 MJ m^{-2} (Holt) in summer compared to 562 and 383 MJ m^{-2} in autumn. Shorter photoperiod and rapidly decreasing light intensity and altered light quality during autumn restrict growth and set limits for production even if temperatures are favourable (Rapacz *et al.*, 2014), and this is accentuated at the northern latitudes. Autumn light conditions may also serve as environmental cues for growth cessation and winter acclimation for the adapted plant species and cultivars used in these trials (Rapacz *et al.*, 2014). Furthermore, we did not fertilise plots after the second cut and low nutrient availability would hamper growth.

Cutting the autumn regrowth in 2016 significantly impaired the DM yields of the first cut in 2017 especially at the northern site. At Løken, the 'normal' autumn cut along with no cut of autumn regrowth gave the highest yields in 2017. At Holt, early second harvest and no cut of autumn regrowth gave the highest yields.

Conclusion

The production in autumn was very low, probably due to decreasing photoperiod and low light causing growth cessation. Leaving the autumn regrowth uncut did not reduce productivity next year in the lowland sites. In the mountain and particularly in the northern site, cutting autumn regrowth after mid-September significantly reduced next year's yield.

Acknowledgements

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Functional evaluation of perennial forage legumes

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Keywords: legume, functional trait, value of use

Introduction

We evaluated the functionality of 13 forage legumes in order to identify new species better adapted to resource limited environments in the context of climate change. The objectives were to conduct agronomic characterisation of productivity, feed value and phenology in order to set the value of use of the different species and to characterise their functioning from leaf traits related to growth strategy.

Materials and methods

Micro plots (2 m^2) were sown in four replicates. Growth stages were scored visually and expressed as the sum of temperature (°C j). Above ground biomass was measured on several dates for radiation use efficiency (RUE, g MJ^{-1}). At blossom, leaf, stem and below ground biomass were measured, as well as organic matter digestibility (OMD), leaf dry matter content (LDMC, mg g^{-1}) and specific leaf area (SLA, m^2 kg^{-1}). Data treatment was performed with ascending hierarchical classification, based on Ward method, which gives the 'best' possible species clustering into a selected number of classes (Cruz *et al.*, 2010).

Results and discussion

According to species, RUE varied between 0.8 g and 2.1 g MJ^{-1}, OMD between 61 and 85%, blooming onset between 653 and 1,356 °C j, LDMC between 140 and 260 mg g^{-1}, and SLA between 19 and 30 m^2 kg^{-1}. We identified five groups in which species share common characteristics and display similar value of use. Group 1: *Anthylis vulneraria* and *Onobrychis sativa* with high RUE, intermediate LSR and OMD, and early bloom are adapted to early use. Group 2: *Lathyrus pratensis, Melilotus officinalis, M. alba, Vicia craca* and *Bituminaria bituminosa* with low OMD and high lateness are suitable for stocks. Group 3: *Lotus corniculatus* and *Trifolium pretense* with high photosynthetic capacity (high RUE and SLA), high LSR and OMD and high below ground above ground ratio are more tolerant to hydric stress. Group 4: *Medicago sativa, Securigera varia* and *Lotus tenuis,* with high RUE and biomass production, low LSR and OMD and very late blooming are suitable for hay stocks. Group 5: *T. repens* with low above and below ground biomass, high LSR and OMD is sensitive to drought and suitable for early grazing.

Conclusion

This study shows the large functioning diversity present within perennial forage legumes and highlights *V. cracca*, *O. sativa* and *L. pratensis* which tend to grow faster and later than cultivated ones and display favorable feeding value.

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Browsing preferences of tall fescue types and a common pasture mixture under cattle grazing

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Abstract

Tall fescue (*Festuca arundinacea* Schreb.) is relatively tolerant of short-term flooding as well as drought and could be a useful species on slightly undulating, heterogeneous fen sites. However, the low voluntary intake by cattle is a great disadvantage but this can be overcome by new soft-leaved varieties. We established two plot trials (plots of 60 m^2) on a moderately moist site and a wet site with four replicates and the following treatments: (i) mixture of soft-leaved new tall fescue varieties, (ii) mixture of hard-leaved common tall fescue varieties, (iii) tall fescue-based *Festulolium*, (iv) ryegrass dominated standard mixture (only at the moderately moist site) and (v) plant stand of the old sward. The plots were rotationally grazed by heifers over two years. After three and five days of grazing, we determined the browsing preferences on the test plots through visual assessment. On average, the preference ranking of the seeded treatments was (iv), (i), (ii), and (iii), but the differences between the last three were small in some cases. Browsing preference and digestibility (gas production estimated by NIR-spectroscopy) were significantly correlated.

Keywords: *Festuca arundinacea*, forage selection, cattle grazing

Introduction

The improvement of productivity and forage quality by the establishment of new plant stands proves to be difficult on sub-optimal grasslands that tend to be wet or dry. The success of common perennial ryegrass (*Lolium perenne* L.)-based mixtures is only short-lived at such sites due to drought in summer and groundwater inundation in winter. Tall fescue (*Festuca arundinacea* Schreb.) is characterised by useful properties concerning forage yield, persistence, cold hardiness and tolerance against drought and wetness (Petersen, 1981; Turner *et al.,* 2012). Thus, it is well adapted to the heterogeneous site conditions of a shallow-undulated type of fen grassland. But, cattle do not like this grass very much because of its rough foliage. New soft-leaved varieties of tall fescue were bred to overcome this disadvantage. We present two-year results of two grazed plot experiments on a fen site including mixtures of soft-leaved and hard-leaved varieties of tall fescue.

Materials and methods

In August 2014, field plots (7.5 × 8 m) were established at a fen location near Paulinenaue, north-west of Berlin, using a randomised block design with four replications. One field trial was placed on a moderately moist site and a second one on a rather wet area (mean Ellenberg moisture value: 5.6 and 6.7, respectively). The following plant stands were included: at the moderately moist site: (i) common grass mixture (17% *Poa pratensis* L., 33% *Phleum pratense* L., 33% *Lolium perenne* L., 17% *Festuca pratensis* Huds.), (ii) mixture of new soft-leaved tall fescue varieties (Barelite, Bariane, Barolex, Bardoux, Otaria), (iii) mixture of common tall fescue varieties (Fawn, Lipalma), (iv) x *Festulolium pabulare* cv. Mahulena, and (v) old sward – *Poa spp./Elytrigia repens*-vegetation type interspersed with a low proportion of the other, former seeded species; at the wet site: treatments as above, but without (i) and the main species of the old sward were: *Phalaris arundinacea* L., *Elytrigia repens* (L.) Desv. ex Nevski, *Poa trivialis* L., *Agrostis stolonifera* L. and *Alopecurus geniculatus* L. The plots received 30 kg P ha^{-1} and 150 kg K ha^{-1} in early spring of each experimental year and were rotationally grazed by heifers of the 'Uckermärker' cattle breed over two years (stocking density during the grazing days was 6.5 LU ha^{-1}). The grazing experiment started with the second growth in 2015. The browsing rate was determined on the third and fifth grazing day through visual assessments. The following rating scale for browsing levels was used: 0: no browsing, 1: top browsing (*ca.* 7% of the plant canopy), 2: half browsing, 3: complete browsing (*ca.* 90 to 95% of the plant canopy). The mean browsing rate per plot was calculated on the basis of the assessed cover percentage of the single browsing levels. In 2016, just before each grazing, the forage quality was determined by NIR-spectroscopy.

Browsing rates were analysed using the MIXED procedure of SAS (version 9.1, SAS Institute, Inc., Cary, NC, USA). Means were compared by Tukey's test ($P < 0.05$). Pearson's correlation was applied to determine the relationship between browsing rate and digestibility.

Results and discussion

The differences between the browsing rates of the test mixtures were significantly influenced by the digestibility of the plant material (parameter: gas production estimated by NIR-spectroscopy, see Table 1).

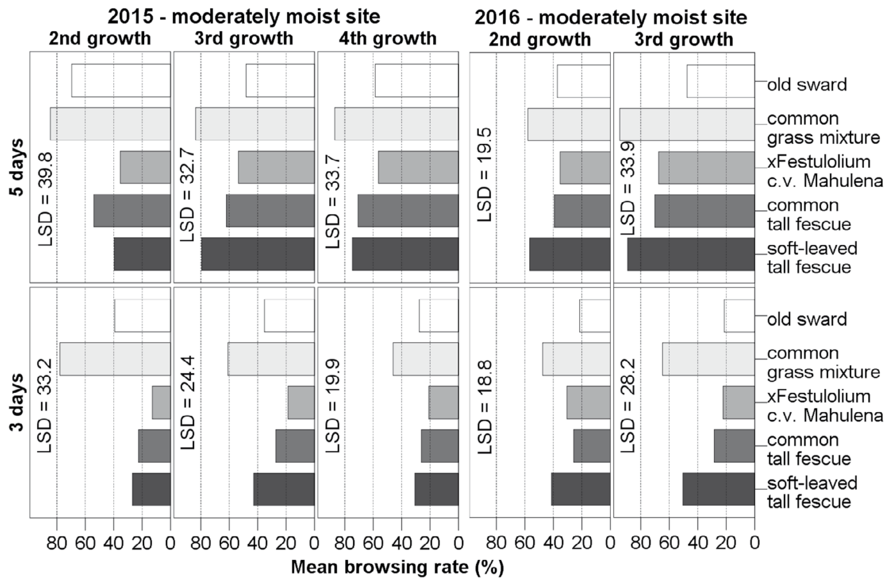
On the moderately moist site, the common grass mixture (i) was significantly preferred by the heifers in the first year of use (Figure 1). The differences between (i) and the other treatments were particularly visible during the first grazing in 2015 and decreased in the following grazing periods. This suggests that the animals adapted to the food range. This hypothesis is also supported by the fact that the browsing rate was higher on the familiar plant stands of the old sward at the beginning of the experiment compared to the following time (Figure 1). The mixture of the soft-leaved tall fescue varieties resulted in a slightly higher browsing rate, on average, than the common tall fescue mixture. The diverging results at the beginning of the experiment are caused by the slow juvenile development of the seeded tall fescue, whereby the different hardiness of the leaves was not yet visible. The tall fescue based *Festulolium* cv. Mahulena tended to result in the lowest browsing rate. Elsäßer *et al.* (2015) found a strong preference for *Lolium perenne* over *Festuca arundinacea* stands after cattle grazing, even if the soft-leaved tall fescue varieties were included. The present experiment resulted in smaller differences between (i) and the other seeded treatments (except during the first grazing in 2015).

Table 1. Correlations (Pearson) between browsing rate after 5 days of grazing and digestibility (gas production); all coefficients are significant at $P < 0.05$.

Moderately moist site 2016		Wet site 2016		
2nd growth	3rd growth	1st growth	2nd growth	3rd growth
0.443	0.886	0.655	0.766	0.668

Conclusion

The differences in forage preferences were rather small. No seeded treatment was fully refused by the grazing animals. Consequently, in the case of forage shortage, it can be expected that the pasture grass residual from all treatments is similarly minimised at the end of a grazing period.



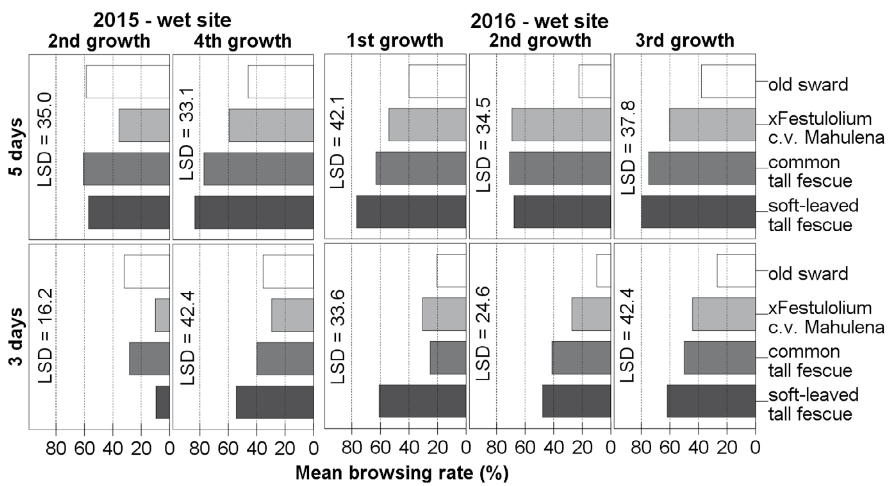


Figure 1. Browsing rates after three and five grazing days. Least significant differences (LSD) at $P < 0.05$.

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Biomass production and forage quality under intensive and extensive grazing

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Abstract

Grazing intensity is considered as one of the most important factors in pasture management. The aim of this study was to evaluate the effect of intensive (IG) and extensive (EG) grazing on sward parameters such as biomass production and forage quality. A two-year study was performed under a long-term grazing experiment in 2005 and 2006 in an upland area in northern Czechia. The swards were maintained at a target height of 5 and 10 cm under IG and EG, respectively. Biomass samples were taken from a movable cage (1 m × 1 m) every three weeks during the vegetation seasons. The majority of measured variables were affected significantly by both sampling date and treatments. A higher concentration of Acid detergent fibre (ADF) and Neutral detergent fibre (NDF) was detected under EG than IG, especially in the summer period. In contrast, IG management had higher crude protein concentration. Additionally, dry matter herbage biomass production was significantly higher under IG and two or three peak biomass production periods were found in early spring and in summer (July/August). EG has shown lower forage quality and lower biomass production, but can still cover feed demand of grazers in grassland dominated upland regions in the Czechia.

Keywords: pasture, grazing intensities, heifers, nutritive value

Introduction

In livestock production, herbage from grassland is one of the most important natural sources of protein and fibre. For a country like the Czechia, with declining livestock population and increasing permanent grasslands (CSO, 2016), alternative ways of managing extensive areas of grasslands is necessary for a strategic planning of the grassland management that secures yield and quality requirements of livestock. It has been widely reported that grazing intensities play a crucial role in pasture management. The aim of this experiment was to study the effect of different grazing intensities on herbage production and quality.

Materials and methods

The study was carried out at Oldřichov grazing experiment located in the Jizera Mountains in the northern part of the Czech Republic, in Oldrichov v Hájích village, at 420 m a.s.l. Since 1998, the experimental site has been continuously stocked with young heifers each year from May to November. Two treatments were applied: (1) extensive grazing (EG), where the stocking rate was adjusted to achieve a mean target sward surface height greater than 10 cm, and (2) intensive grazing (IG), in which the stocking rate was adjusted to achieve a mean target sward surface height of less than 5 cm (Ludvíková *et al.,* 2015). The sward height in IG is maintained by four heifers and for EG by two heifers. The mean stocking rate were approximately 500 kg ha^{-1} and 1000 kg ha^{-1} for EG and IG treatments, respectively. In the years 2005 and 2006, forage biomass were measured every three weeks, from four movable ex-closure cages (1m × 1m) which were installed in each treatment paddock throughout the grazing season. Subsequently, the samples were weighed and dried for 48 hours at 85 °C for dry matter (DM) yield assessment and then analysed for crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF) and ash contents. Data was analysed using repeated measures of ANOVA to evaluate the effect of grazing on forage production and quality during the growing season.

Results and discussion

The analyses revealed similar patterns of biomass growth in both grazing treatments, but were higher under IG treatment (Figure 1a) in both years. A significant difference between treatments was observed and two peak biomass production periods in spring and summer were recorded in both years. It is reported that a double peak curve in the same site has occurred nine times in a 14 year grazing experiment (Kassahun, 2016). It can be concluded that a curve for aboveground biomass production with a double peak is more typical in Czechia. Finally, DM biomass yield was higher in 2005 in both treatments (IG = 446 g kg^{-1}, EG = 369 g kg^{-1}) than in 2006 (IG = 371 g kg^{-1}, EG = 274 g kg^{-1}). These results can partially be explained by the different precipitation trend between the two years. During the growing season (April – Oct), the total amount of rainfall was 1,248 mm (2005) and 759 mm (2006).

Grazing intensity had a significant effect on forage quality, as the CP concentration was higher under IG in both years. For both fibre (ADF and NDF) the reverse was true where it was higher under EG. Treatment and date effect were significant in all tested variables with the exception of ash in 2006 (Table 1). ADF and NDF contents were lower during the early spring before rising to higher level during the summer period and falling again at the beginning of autumn. The CP concentration and ash followed the reverse pattern with high levels during the spring under IG and decreasing during the summer before increasing again in autumn. Seasonal variation in CP concentration was similar for both grazing treatments during the years (Figure1b). Seasonal variation of ADF and NDF content is dependent on the development stage of the pasture species.

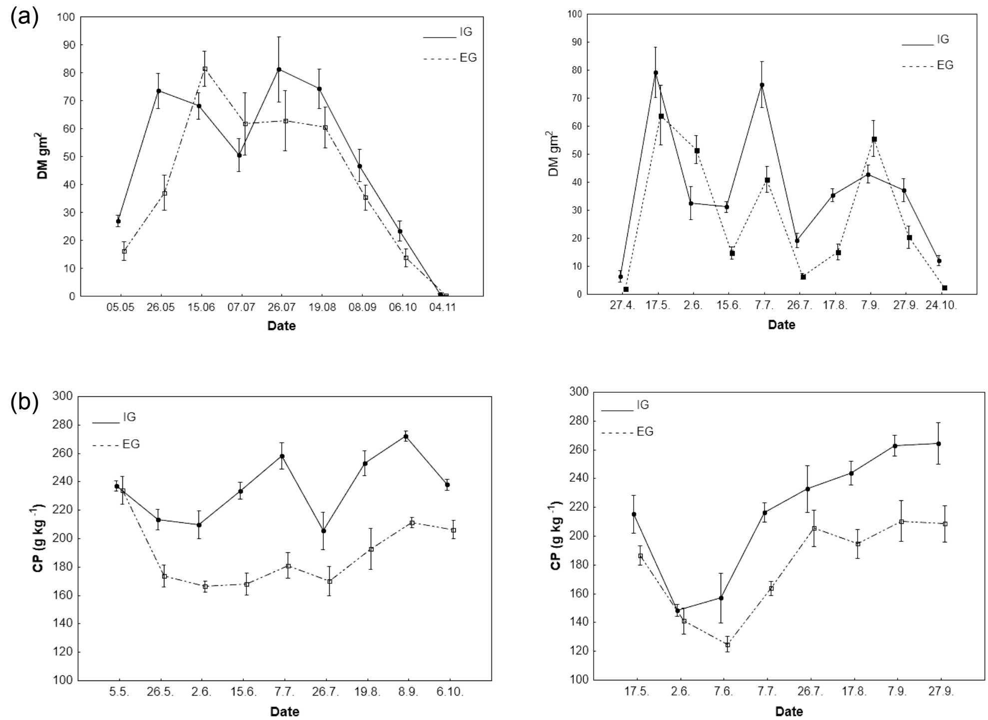

Figure 1. Seasonal variation of dry matter biomass yield (a) and Crude protein (b) under Intensive Grazing and Extensive Grazing treatments in the years 2005 and 2006.

Table 1. Results of repeated measurements – ANOVA analyses of nutrients content in pasture forage. Abbreviations Neutral detergent fibre (NDF), Acid detergent fibre (ADF) and Crude protein (CP).

	Effects	NDF		ADF		CP		ASH	
		F	*P*	*F*	*P*	*F*	*P*	*F*	*P*
2005	Treatments	22.93	<0.001	62.72	<0.001	139.9	<0.001	10.23	0.002
	Date	2.86	0.010	20.6	<0.001	12.10	<0.001	14.43	<0.001
	Treatments × Date	0.88	0.543	2.22	0.040	3.60	0.002	1.66	0.130
2006	Treatments	16.16	<0.001	51.43	<0.001	48.85	<0.001	0.05	0.831
	Date	3.17	0.008	11.86	<0.001	23.89	<0.001	17.87	<0.001
	Treatments × Date	1.04	0.413	2.31	0.041	1.22	0.310	2.91	0.013

F represents value derived from F statistics in repeated measurements of ANOVA and *P* represents related probability value.

As plant matures, ADF increases (Demarquilly, 1989). This accounts for the higher ADF content under EG in our experiment. Similarly, NDF increases as the plant matures, probably because the accumulation of stem mass exceeds the increment of leaf mass and therefore, the leaf: stem ratio decreases (Elgersma and Soegaard, 2016). For CP, the concentration level increases as stocking density increases, this is because of limited time for regrowth and high grazing intensity. This, in turn, increases the CP concentration as flowering is reduced. Increasing leaf to stem ratio in herbage (Overman and Wilinson, 1990), means higher CP concentration in leaves than in stem (Norton, 1982).

Conclusion

Extensive grazing has shown lower biomass production and lower forage quality but it can still be a useful management for grassland-dominated countries with insufficient livestock population like in the Czech Republic.

Acknowledgements

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Dry matter yield and plant density of alfalfa as affected by cutting schedule and seeding rate

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Abstract

Alfalfa cutting schedule is a more significant factor in achieving high quality, high yields and stand persistence than numerous cultural practices such as irrigation, fertilisation, pest control, sowing management, variety selection, etc. The objective of this research was to determine dry matter (DM) yield and plant density of alfalfa stand as affected by the three different cutting schedules: C 1 - early (first flower, 5 cuts), C 2 - medium (late flower, 4 cuts), and C 3 - late (green pod, 3 cuts), and two seeding rates: S1-8 kg ha^{-1} and S2-16 kg ha^{-1}, during 2009 - 2011. The numbers of plants per square metre were determined six weeks after sowing, in the spring 2010 and in spring 2011. In each year and over a two year total, C 3 had significantly lower DM yield than other treatments. Alfalfa harvested at the C 1 stage produced higher total DM yield (45.0 t ha^{-1}) than harvesting at the C 3 stage (36.4 t ha^{-1}). Cutting schedule did not influence plant populations of alfalfa stand. The final plant densities were approximately the same in all cutting treatments (early - 90; medium - 85; late - 90 plants m^{-2}). The analysed agronomic traits were not significantly affected by seeding rate.

Keywords: alfalfa, cutting schedule, plant density, seeding rate, yield

Introduction

Alfalfa (*Medicago sativa* L.) is very highly regarded as a forage crop because of its high adaptability, great yield potential and high nutritional value. The forage yield of alfalfa depends on many factors, primarily on growing conditions, cultural practices and varieties. Moreover, harvest timing is the most powerful tool under the alfalfa grower's control to impact yield and quality. Alfalfa maturity at time of cutting strongly influences dry matter (DM) yield (Orloff and Putnam, 2010). Cutting at later stage (full flower) increased DM yield by 18% when compared with earlier cutting (first flower), whilst prolonging the productive life of the alfalfa field (Lloveras *et al*., 1998). Alfalfa cut at earlier stages (i.e. pre-bud or early bud) has high forage quality but DM yield reduces. Conversely, alfalfa cut in the later stages (flowering) is higher yielding but lower forage quality (Orloff and Putnam, 2006). According to Sheaffer *et al.* (1988), cutting at the first flower stage generally resulted in the best combination of seasonal herbage and nutrient yield and persistence. The successful establishment of an alfalfa stand depending on seeding rate has long been a focus of studies. According to Bradley *et al.* (2010), planting alfalfa at different seeding rates from 4.5 to 18 kg ha^{-1} do not produce higher DM yield. The objective of this research was to determine the DM yield and plant density of an alfalfa stand under three cutting schedules and two seeding rates.

Materials and methods

The trial was carried out at the Experimental Field of Institute of Field and Vegetable Crops in Novi Sad, Serbia. The soil was a chernozem with good physical properties (pH 7.5 in KCl, 6.4% $CaCO_3$, 23.5 mg P_2O_5 100g^{-1} and 40.0 mg K_2O 100g^{-1} of soil). The experiment, a randomised complete block design with three replications in a split-plot arrangement, was set up in the spring of 2009. The experimental treatments included i) two seeding rates: S1-8 and S2- 16 kg ha^{-1} and ii) three cutting schedules at different phenological stages, according to Kalu and Fick (1981): C 1 - early (first flower, 5 cuts), C 2 - medium (late flower, 4 cuts) and C 3 - late (green pod, 3 cuts). During the 2010 - 2011 influence of investigated factors on DM yield (t ha^{-1}) was tested. Plant density was determined by counting the number of live plants in randomly placed quadrat (1 m^2) in each plot. The initial counting of plants was performed at the five trifoliate leaf stage, then in the spring of 2010 and 2011. Green forage yield was determined by cutting the plot area and the fresh weight was determined immediately. The plots were cut at a stubble height of 7 cm, using the forage harvester Cibus. Subsamples of 300 g from each plot were weighed fresh and again after drying for 96 h in a forced-air oven at 50 °C to determine DM content. The annual and two year total DM yield was calculated by summing the individual cuts annually for the two year period. The four alfalfa cultivars used in the experiment (Banat VS, Nijagara, NS Alfa i NS Mediana ZMS V) did not show statistically significant differences in tested variables so the data are not reported. Results were analysed by the analysis of variance and tested by the LSD test.

Results and discussion

Of the two factors used in this experiment, seeding rate and cutting schedule, the latter had a significant effect ($P < 0.01$) on DM yield of alfalfa. Early cutting (C 1) had the greater DM yield (20.7 t ha^{-1}) in 2010, while in 2011 the greater DM yield was obtained with the medium (C 2) cutting schedule (24.6 t ha^{-1}). In 2010 and 2011 and over a two year total, there is no DM yield difference between cutting at C 1 and C 2 stage, while the cutting at C 3 stage had significantly lower DM yield than other treatments (Table 1). These results are in line with Scheaffer *et al.* (2000), who found that cutting frequency, or more accurately, the maturity of the alfalfa at the time of harvest, determines forage yield. Seeding rate did not affect DM yield. In both production years, increasing seeding rate did not result in significant increases in the DM yield of alfalfa, which is in agreement with Heerden (2012), who found no DM yield increase with increasing alfalfa seeding rate from 6 to 12 kg ha^{-1}. The DM yields and plant density obtained under three cutting schedules over two seasons are presented in Table 1.

In this study, both higher seeding rate and more frequent cutting of stand did not increase density of alfalfa plants (Table 2). Plant density, six weeks after sowing, was 9% higher for S1 (290 plants m^{-2}) than S2 (263 plants m^{-2}). The difference was not statistically significant. In spring 2010, both seeding rates had similar densities (210 and 213 plants m^{-2}) and in 2011 (year 3), plant density was 88 plants m^{-2} for both seeding rates.

Results obtained in our study support the findings of Hall *et al.* (2010), who claimed that there is no significant impact of higher seeding rates on density of alfalfa plants. Plant density, with all cutting schedules, decreased over the three years of investigation. In the spring of 2010, plant density averaged 201, 203 and 230 plants m^{-2}, for C 1, C 2 and C 3. There were no differences among the cutting schedules. In 2011, plant densities were approximately the same in all cutting treatments (C 1 - 90; C 2 - 85; C 3 - 90 plants m^{-2}), so taking three, four or five cuts per year did not affect plant density.

Table 1. Effect of cutting schedule (C) on dry matter yield (t DM ha^{-1}) and plant density (number of plants m^{-2}) of alfalfa stand during 2009 - 2011.

Cutting schedule (C)	DM yield (t ha^{-1})			Plants m^{-2}		
	2010	2011	2-year total	Initial plant density (29 June 2009)	29 March 2010	Final plant density (15 March 2011)
C 1	20.7**	24.3**	45.0**	281^{NS}	201^{NS}	90^{NS}
C 2	19.8**	24.6**	44.4**	274^{NS}	203^{NS}	85^{NS}
C 3	17.9	18.5	36.4	275^{NS}	230^{NS}	90^{NS}
lsd	1.6	1.4	1.9	52	34	7

NS - non significant; * significant $P < 0.05$; ** significant $P < 0.01$.

Table 2. Effect of seeding rate (S) on dry matter yield (t DM ha^{-1}) and plant density (number of plants m^{-2}) of alfalfa stand during 2009 - 2011.

Seeding rate (S)	DM yield (t ha^{-1})			Plants m^{-2}		
	2010	2011	2-year total	Initial plant density (29 June 2009)	29 March 2010	Final plant density (15 March 2011)
S1	19.1^{NS}	22.7^{NS}	41.8^{NS}	290^{NS}	210^{NS}	88^{NS}
S2	19.9^{NS}	22.3^{NS}	42.2^{NS}	296^{NS}	213^{NS}	88^{NS}
lsd	0.9	0.8	1.2	42	28	6

NS - non significant; * significant $P < 0.05$; ** significant $P < 0.01$.

Conclusion

Cutting schedule or seeding rate did not influence alfalfa plant density. Results of these investigations showed that cutting schedule had a significant effect on DM yield of alfalfa. This factor did not influence plant density. The more frequent cutting did not cause thinning of alfalfa stand. In both production years, alfalfa harvested at the early flower stage produced higher DM yield than harvesting at the green pod stage.

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The effect of pre-graze mowing at different pre-graze masses on cow and pasture performance

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Abstract

Early lactation cows were allocated to one of four treatments in a replicated 2 × 2 factorial study. Treatments were two pre-graze pasture masses: moderate (2,800 kg DM ha^{-1} to ground level; MOD) and high (3,400 kg DM ha^{-1}; HIGH) and two harvesting methods: grazing standing pastures (G), or mowing before grazing (M). Mowing before grazing did not alter milk solids (fat + protein) production, or body condition score. However, M reduced pasture density and pasture harvested. Consistent with this, less silage was conserved and more silage fed in M compared with G. Irrespective of harvesting method, cows in MOD produced 6% more milk solids than cows in HIGH. There were minimal differences in the nutrient composition of pasture from MOD and HIGH, but cows in MOD spent less time grazing than in HIGH. In summary, there was no animal performance benefit from M in either MOD or HIGH; however, M reduced pasture eaten and increased the requirement for imported feed. Furthermore, irrespective of harvesting method, cows offered a MOD pre-graze pasture mass produced more milk solids than those offered a HIGH pre-graze mass.

Keywords: grazing, mowing, pasture mass, milk solids

Introduction

Environmental constraints in grazing systems have added to the challenges of improving farm performance by limiting land area and/or cow numbers. In response, some farmers target higher than recommended pre-graze pasture masses (i.e. > 3,200 kg DM ha^{-1} to ground level), with an associated belief that this will increase pasture grown, but that mowing before grazing is required to harvest this extra pasture. Earlier research indicated little or no benefit of mowing before grazing on milk solids (fat + protein) production, with immediate effects including reduced dry matter intake (DMI), pasture growth and silage conservation (Kolver *et al.*, 1999; Bryant *et al.*, 2016). However, these studies did not investigate the longer-term impact of continuous mowing during spring and summer in systems with greater than recommended pre-graze pasture masses.

Materials and methods

The present experiment was conducted at the Lincoln University Research Dairy Farm, Canterbury, New Zealand (NZ). In October 2016, 136 early-lactation, primiparous and multiparous Friesian × Jersey cows were randomised into eight farmlets for 120 days. Farmlets were randomly allocated to one of four treatments in a replicated 2 × 2 factorial study. Treatments consisted of two pre-graze pasture masses (2,800 kg DM ha^{-1}; to ground level; MOD vs 3,400 kg DM ha^{-1}; HIGH) and two harvesting methods (grazing standing pastures; G vs mowing before grazing; M). Paddocks within each farmlet consisted of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) pastures and were balanced for soil type, pasture age, ploidy and previous management. All farmlets were offered the same daily pasture allowance. Daily area offered (rotation length) varied between MOD and HIGH to achieve target pre-graze masses, target post-graze residual (3.5 - 4 cm compressed height on a rising plate meter; RPM), and cow DMI. Paddocks in M were mown approximately 1 h before grazing using a UFO twin-drum mower (no conditioner) with blade height set to achieve target residuals. If pasture allocation was below target and the area offered could not be increased sufficiently, cows were supplemented with pasture silage to meet intake requirements. If pre-graze pasture mass was greater than 5% above target, paddocks were closed and harvested for silage. Individual milk yields were recorded daily and milk composition determined weekly. Body condition score (BCS) was measured fortnightly. Daily grazing and ruminating times were determined in four cows per farmlet using eartags containing motion sensors (Sensoor). Pre- and post- graze heights were measured for each grazing using an RPM and calibrated equations determined for each treatment (Bryant *et al.*, 2016). Pasture residuals from mown paddocks were collected and weighed weekly. Representative pre- and post- graze pasture samples were collected weekly by cutting standing pastures to ground level and analysed for botanical and nutritive composition (Bryant *et al.*, 2016). All data were analysed with mixed models fitted using REML in GenStat 16.0 (VSN International, 2013). Pre-graze mass, harvesting method and their interaction were included as a fixed effect and week within treatment were included as random effects. Differences were considered significant at $P < 0.05$ and a trend declared at $P < 0.10$.

Results and discussion

Animal and pasture measurements are presented in Table 1. To achieve target pre-graze masses, the rotation length was eight days longer in HIGH compared with MOD. Calibration equations derived for each treatment throughout the experiment indicated that there was less kg DM ha^{-1} available at a given height in M relative to G. This is consistent with Bryant *et al.* (2016) and resulted in a trend ($P = 0.05$) for pre-graze pasture mass to be less in M vs G. Mowing achieved target post-grazing residuals (3.5 - 4 cm) while G had greater residuals (4.5 - 5.0 cm). However, post-mown residuals indicated some mown pasture was not harvested and remained lying in the paddock after the cows had finished grazing (Table 1).

There was no difference in total milk solids production or BCS change between M and G. This is consistent with previous studies (Kolver *et al.*, 1999 and Bryant *et al.*, 2016) that reported little or no improvement in animal performance when mowing before grazing was compared with grazing standing pastures for short periods. In the current study, continuous mowing of pastures reduced pasture performance (Table 1). Pastures that were mown before grazing were less dense (less kg DM ha^{-1} available for a given height) compared with those that were grazed. Although no significant difference was detected in daily pasture growth rates, estimated DMI from pasture was lower (14.3 vs 15.6 kg DMI per cow day^{-1}; $P < 0.05$), and more silage (0.5 vs 0.1 t DM ha^{-1}) was fed to meet allocation targets in M. In addition, less

Table 1. Effect of harvesting method (mowing before grazing; M vs grazing standing pasture; G) at HIGH (3,400 kg DM ha^{-1}) and MOD (2,800 kg DM ha^{-1}) pre-graze pasture mass on farm system variables.

Variable	Treatment				SED	*P*-value		
	HIGH-G	HIGH-M	LOW-G	LOW-M		Mass	Harvesting	M × H
Fat yield (kg d^{-1})	0.99	1.00	1.04	1.07	0.02	<0.01	0.29	0.38
Protein yield (kg d^{-1})	0.76	0.77	0.84	0.83	0.02	0.01	0.82	0.69
Estimated total DMI (kg d^{-1})[1]	15.8	15.7	15.8	15.3	0.6	0.54	0.45	0.68
BCS change (1 - 10 scale)	-0.14	-0.12	-0.13	-0.18	0.08	0.66	0.81	0.55
Rotation length (d)	29	28	21	21	0.3	<0.01	0.59	0.04
Pre-graze mass (kg DM ha^{-1})	3,446	3,156	2,890	2,705	49	<0.01	0.05	0.33
Post-graze mass (kg DM ha^{-1})[2]	1,820	1,499	1,790	1,615	18	<0.01	<0.01	0.04
Post-mow mass (kg DM ha^{-1})[3]		190		143	86.5		0.39	
Silage fed (t DM ha^{-1})	0.07	0.49	0.09	0.48	0.03	0.98	<0.01	0.72
Silage harvested (t DM ha^{-1})	0.55	0.07	0.39	0.00	0.04	0.15	<0.01	0.54

[1] Estimated total DMI = sum of pasture DMI (pre - minus post-grazed and mown mass / area grazed / number of cows) plus silage intake (kg per cow d^{-1}).

[2] Residual mass of standing pasture.

[3] Residual mass of mown pasture.

silage was conserved (0.05 vs 0.5 t DM ha^{-1}) from M compared with G (Table 1). The lower estimated DMI, pasture production and silage conservation is consistent with previous studies (Kolver *et al.,* 1999, Bryant *et al.*, 2016) and confirms the negative effect of continuous mowing on pasture performance. There were no consistent differences in botanical or nutrient composition of pasture between M and G (data not presented). Irrespective of harvesting method, cows in MOD produced 6% more milk solids than those in HIGH (Table 1). The lower milk solids production with increasing pasture mass is consistent with previous studies (McEvoy *et al.,* 2009; Curran *et al.,* 2010). These studies attributed the reduced production to a lower pasture quality (increased dead material and fibre and reduced crude protein, digestibility and metabolisable energy; ME) with the higher herbage mass. However, in the current study, there was no consistent effect of pre-graze pasture mass on pasture quality (digestibility, fibre or ME). An alternative explanation may be that there was less pasture available between 2.5 and 5 cm in HIGH. Perez-Prieto and Delagarde (2012) proposed this as a reason for reduced milk yield with increasing herbage mass above 5 cm. In the current study, allocated grazing areas for cows in HIGH were 30% less than for cows in MOD, which would reduce available herbage between 2.5 and 5 cm and may have contributed to the reduced milk production in HIGH. Cows in HIGH also spent an extra 42 mins d^{-1} grazing compared with those in MOD, which is possibly an attempt to counter a reduced intake rate from grazing more mature pastures.

Conclusion

Cows offered a moderate pre-graze pasture mass (2,800 kg DM ha^{-1}) produced more milk solids than those offered a higher pre-graze pasture mass (3,400 kg DM ha^{-1}), and this was not affected by mowing pastures before grazing. Importantly, continuous mowing of pastures reduced pasture performance and increased the requirement for imported feed.

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Forage grasses effectively use soil P-pools in low-P_{AAC} soils in Finland

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Abstract

In Finland, recent studies have rarely indicated a grass DM yield response to phosphorus (P) fertilisation on mineral soils. In this study, yield responses to P fertilisation and effectiveness of cattle slurry as a P fertiliser were studied on soils with low level of soil acid ammonium acetate-extractable P (P_{AAC} < 10 mg l^{-1}). Two 3-year field experiments were conducted, one with a mixture of Timothy (*Phleum pratense* L.*)* and Meadow fescue (*Festuca pratensis* Huds.) on loam (4.6 mg P_{AAC} l^{-1}) in central Finland, and the other with Timothy on organic soil (8.3 mg P_{AAC} l^{-1}) in northern Finland. Both experiments were established with barley (*Hordeum vulgare* L.) as a cover crop. The experiments were carried out as a split plot design. The effect of cattle slurry (30 Mg ha^{-1}), mineral fertilisation (0, 10, 20, 40 kg P ha^{-1} $year^{-1}$) and their interaction on grass DM yield, nutritional values (organic matter digestibility, P concentration, P/nitrogen ratio) and P balance were determined. Grass yield response to P fertilisation was low and detected only in the third year. The effect was the same in both main plots (slurry/no slurry). Phosphorus fertilisation increased the P content of grass DM, especially in the first cut. The results indicate that forage grasses can extract soil P effectively, despite low levels of P in the soil.

Keywords: grass, phosphorus, nutritive value of grass, silage, cattle slurry

Introduction

Phosphorus (P) is an essential nutrient for plant growth. A strongly positive P balance together with P accumulation in the topsoil can increase the risk of P leaching. The use of P fertiliser and slurry application are regulated by agri-environmental schemes in Finland, where Baltic seas and lakes are vulnerable to P losses. A recent meta-analysis of Finnish P fertilisation studies suggested that a yield response is likely if the soil acid ammonium acetate-extractable P ($P_{AAC)}$ concentration (Vuorinen and Mäkitie, 1955) is lower than 6 mg l^{-1}, 10 mg l^{-1} or 15 mg l^{-1} in clay, coarse textured mineral soil and organic soil, respectively (Valkama *et al.*, 2016). Some recent (since 2000) P fertilisation studies have indicated the absence of a yield response, contrary to the meta-analysis. The experiments included in the meta-analysis did not include P from animal manure, although it is an essential part of P in grassland farming. In this study, our aim was to investigate yield and soil P_{AAC} responses of mineral P fertilisation and cattle slurry on organic soils and easily compacting loam soils with a low level of soil P_{AAC}.

Materials and methods

The study was carried out as a split plot experiment in Maaninka (63°08' N, 27°19' E, loam, P_{AAC} = 4.6 mg l^{-1}), and Ruukki (64°41' N, 25° 9' E, organic soil, P_{AAC} = 8.3 mg l^{-1}), Finland, during the growing seasons of 2015 to 2017. Plots were established in 2015 in four replicates using a mixture of Timothy (*Phleum pratense* L.) and meadow fescue (*Festuca pratensis* Huds.) at Maaninka, and Timothy at Ruukki. Barley (*Hordeum vulgare* L.) was used as a cover crop. Fertilisation treatments were also carried out for the cover crop but the results of the whole crop are not presented in this paper. The effect of cattle slurry, compared with mineral nitrogen (N) and P was investigated as the main plot. The mineral N fertilisation was divided between the first, second and third cut, according to agri-environmental schemes, as follows: Maaninka 100, 80 and 50 kg N ha^{-1} and Ruukki 80, 70 and 40 kg N ha^{-1}. Approximately 30 t ha^{-1} of slurry (17 kg P ha^{-1}, 70 to 133 kg ha^{-1} total N and 38 to 81 kg ha^{-1} soluble N) was injected for the second cut and complemented with fertiliser N to correspond to the amount of soluble N in the main plot without slurry application. Mineral P fertilisation (0, 10, 20 and 40 kg ha^{-1} for the first cut) was the subplot. Dry matter yield (kg DM ha^{-1}) was measured from each cut. Digestibility (D value, digestible organic matter; g kg^{-1} DM) and the N concentration of the grass (g kg^{-1} DM) were determined by near infrared spectroscopy and the P concentration of the grass was determined with X-ray fluorescence (Valio Ltd). Soil samples (0 to 20 cm) were taken from each plot in June 2015 and September 2017. Soil P_{AAC} was determined by Eurofins Viljavuuspalvelu Oy (Vuorinen and Mäkitie, 1955). Statistical analyses were performed using Mixed-procedure in SAS 9.3. Experimental sites and cuts were analysed separately.

Results and discussion

Phosphorus fertilisation increased the total DM yield significantly only in Ruukki in 2017 (+ 500 kg DM ha^{-1} y^{-1}). In separate cuts, yield responses to P fertilisation were observed only twice: in Maaninka in 2017 for the second cut (+ 200 kg DM ha^{-1}), and in Ruukki in 2017 for the first cut (+ 400 kg DM ha^{-1}). Over the years, significant differences between treatments were negligible in practice (Table 1 and 2). These results differ from what was expected based on the measured soil P levels of 0 P plots (Valkama *et al.*, 2016). Slurry application most likely caused harm to grass growth in Maaninka due to poor soil conditions at application, and decreased DM production significantly. The study will continue for one more production year and hence, the responses to P fertilisation could become more apparent in later years.

The P concentration of grass varies with the physiological age, leaf/stem-ratio and environmental conditions (fertilisation, moisture, soil P level, etc.). It is also strongly related to N availability (Belanger *et al.*, 2017). The P/N ratio has been used to predict P deficiencies in forage grasses and other crops better than P concentration alone (Belangér *et al.*, 2017). In our study, the N/P ratio did not explain the DM production results or the P response differences between Maaninka and Ruukki. Most likely the reason for the N/P difference between the sites was the high soil N availability at Ruukki. Over the years, P fertilisation significantly increased the P concentration of grass yields in all cuts in Ruukki, especially without slurry application (+ 0.2 g kg^{-1}, + 0.3 g kg^{-1} and + 0.3 g kg^{-1}) DM compared to 0 P plots, respectively. In Maaninka, a slight increase was observed only for certain years and cuts. Without slurry application, the total P balances, i.e. differences between P input and output, were generally negative. The exception was with the P rate of 40 kg ha^{-1} at both sites (Table 1). Slurry application increased the P balance so that it was less negative or positive. The P balances in relation to P applied were similar for mineral P and slurry P. The soil P_{AAC} level increased with P fertilisation. In September 2017, there were no differences in soil P_{AAC} level between the slurry and no slurry plots, but mineral P fertilisation

Table 1. The effect of slurry and mineral phosphorus (P) rate on total dry matter (DM) yield and total P balance during experiment years 2016 and 2017. Site M = Maaninka; site R = Ruukki; mp = no slurry/slurry; sp = mineral fertilisation (0, 10, 20, and 40 kg P ha^{-1} $year^{-1}$), y = year, SEM = standard error of mean.

	Site	No slurry mineral P rate (kg ha^{-1} y^{-1})				Slurry mineral P rate (kg ha^{-1} y^{-1})				SEM	*P*-values						
		0	10	20	40	0	10	20	40		mp	sp	y	mp × sp	y × mp	y × sp	y × mp × sp
DM yield	M	9.7	9.6	9.6	9.7	9.2	8.9	9.0	9.2	0.12	***	***	**	ns	***	ns	ns
t DM $ha^{-1}y^{-1}$	R	12.4	12.4	12.7	13.0	12.5	12.5	12.5	12.3	0.18	ns	ns	***	*	**	ns	ns
P balance	M	-29	-19	-10	9	-6	4	13	31	0.9	*	***	***	ns	*	*	ns
kg P ha^{-1} y^{-1}	R	-33	-25	-15	2	-20	-10	0	19	0.8	***	***	***	**	***	*	*

***($P < 0.001$), **($P < 0.01$), *($P < 0.05$), o($P < 0.10$), ns ($P > 0.10$).

Table 2. The effect of fertilisation on dry matter (DM) yield, digestibility (D value), phosphorus (P) concentration and P/nitrogen (N) ratio of the second cut during experiment years 2016 and 2017. Site M = Maaninka; site R = Ruukki; mp = no slurry/slurry; sp = mineral fertilisation (0, 10, 20, and 40 kg P ha^{-1} y^{-1}); y = year; SEM = standard error of mean.

	Mineral P rate kg ha^{-1} y^{-1}	DM yield, t DM ha^{-1} y^{-1}		D-value g kg^{-1} DM		P conc. g kg^{-1} DM		N/P ratio	
Site		M	R	M	R	M	R	M	R
No slurry	0	2.9	4.7	696	653	3.4	2.8	8.7	9.5
	10	2.9	4.7	698	650	3.4	2.9	8.8	8.9
	20	3.0	4.8	694	657	3.5	2.9	8.3	9.2
	40	3.1	5.0	694	654	3.5	3.1	8.0	8.4
Slurry	0	2.3	4.6	701	658	3.6	3.2	8.9	8.4
	10	2.7	4.5	700	666	3.7	3.1	9.2	8.6
	20	2.7	4.4	702	656	3.7	3.1	8.6	8.1
	40	2.4	4.3	701	658	3.8	3.2	7.9	8.2
SEM		0.06	0.14	3.2	3.1	0.12	0.07	0.30	0.21
P-values	Slurry (mp)	***	*	**	**	***	*	ns	***
	P-fert (sp)	***	ns	*	ns	ns	**	*	*
	Year	**	***	ns	***	*	***	**	***
	mp × sp	ns	*	ns	*	ns	*	ns	*
	Y × mp	***	ns	***	ns	***	***	ns	**
	Y × sp	ns	ns	ns	ns	*	*	*	ns
	Y × mp × sp	ns	ns	ns	ns	ns	ns	ns	ns

***($P < 0.001$), **($P < 0.01$), *($P < 0.05$), o ($P < 0.10$), ns ($P > 0.10$).

increased the P_{AAC} level in the topsoil significantly (from 3.8 mg l^{-1} to 5.2 mg l^{-1} in Maaninka, and from 7.8 mg l^{-1} to 10.3 mg l^{-1} in Ruukki). During the experiment, the P_{AAC} level of the no slurry 0 P-treatment decreased by 1.8 mg l^{-1} in Maaninka and by 0.4 mg l^{-1} in Ruukki.

Conclusion

The results indicate that forage grasses can extract soil P effectively despite low levels of P in the soil. Contrary to current theory, the N/P ratio did not explain the results of DM production, and no yield response to P fertilisation was found. Plant uptake efficiency did not differ between slurry P and mineral P.

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Botanical composition of grassland for silage in mountain districts of Norway

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Abstract

Knowledge about the botanical composition of grassland for silage is important regarding composition of seed mixtures, control of weeds, choice of harvest times and feeding strategies. The botanical composition of 185 fields in the mountain regions of southern Norway was examined using the dry-weight rank method. The survey shows that the youngest grasslands (age 1 - 3 years) were dominated by the sown species with *Phleum pratense* L. the species with the highest proportion in the sward. In 4 - 6 year old grasslands, the proportion of sown species was reduced with the exception of *Poa pratensis* L., and *Elytrigia repens* L. had the highest proportion of unsown species. The proportion of *Festuca pratensis* (Huds.) was reduced at the same rate as *Phleum pratense* L. In grasslands of greater age (> 6 years) *Poa pratensis* L. and *Elytrigia repens* L. had the highest occurrence. The content of herbs increased with age, and *Ranunculus repens* L. and *Taraxacum officinale* F.H. Wigg were the most frequent species. The average clover content was < 6% of DM yield. The impact of *Elytrigia repens* L. on forage yield and quality should be further examined due to the high occurrence. *Poa pratensis* L. or other long-lasting grass species should be included in seed mixtures for this region when the grassland is intended to last more than three years.

Keywords: grassland, Norway, species, succession, *Elytrigia repens*

Introduction

Perennial grassland dominates the land use of cultivated areas in the mountain districts of southern Norway. The proportion of old grassland (> nine years after establishment) was 23% in 2010 (SSB, 2017). The grassland is generally dominated by sown species in the first years after establishment, however, the botanical composition changes with increasing age. Knowledge about the botanical composition of grassland is important regarding composition of seed mixtures, control of weeds, choice of harvest times and feeding strategies. In the project 'Agronomy in mountain agriculture' we have undertaken a survey of botanical composition of grasslands in mountain districts to gain more information on species succession.

Materials and methods

The botanical composition of grassland fields was examined in the period 2013 - 2016 in five districts – Valdres and Ottadalen in Oppland county, Nord-Østerdal in Hedmark county, Oppdal in Sør-Trøndelag county and Lierne in Nord-Trøndelag county. The selection of fields was made by local advisers from the Norwegian Agricultural Extension Service. Fields sown with *Phleum pratense*-based seed mixtures, which dominate the seed market in this region, were selected. In addition we wanted fields of different ages. We grouped the fields into three classes; 1 - 3 years after establishment, 4 - 6 years and greater than six years old. All farms did not have fields in all age classes; in total 85, 58 and 52 fields were examined in the three age classes respectively. Typical grassland fields for the district were chosen with normally a two-cut harvesting system for silage, and a fertiliser plan with typical values of 120 - 220 kg nitrogen ha^{-1} and $season^{-1}$ (both mineral fertiliser and manure). Dairy farms accounted for 72% of the fields and sheep farms for 28%. On sheep farms, many fields were grazed in spring, and autumn grazing is common practice for sheep in the district. Fields on dairy farms were not grazed in spring. Botanical composition was assessed using the 'dry-weight-rank' method (t'Mannetje and Haydock, 1963). Twenty to 40 points in each field were chosen at random by throwing a 50 × 50 cm frame. Within the frame, the three most frequent species were ranked on basis of DM yield. We used the weighting factors 0.7 – 0.2 – 0.1 for the three species in accordance with t'Mannetje and Haydock (1963). With a high dominance of a single species we used multiple ranks for this species. For example, with a total dominance, one species got the rank 123. Most of the fields were botanised in spring, the rest in the autumn for practical reasons.

The botanical composition measurements were collected in MS Excel where the average proportion of all recorded species was calculated for all fields. A variance analysis was undertaken by using the GLM procedure in Minitab according to the model below:

Proportion of a species = Field + age class + error, where field is random variable.

Results and discussion

Table 1 gives the mean values of all fields. Behind the mean values there was a considerable variation amongst fields, especially in the oldest age group. The proportion of *Poa pratensis* L. and *Elytrigia repens* L. was very variable with both domination and absence of the species in individual fields. The proportion

Table 1. Proportion of species (%) estimated on dry matter basis in silage fields in mountain districts of southern Norway. Mean value of all fields grouped in three age classes.

		Age of the fields			*P*-value
		1 - 3 year	4 - 6 year	above 6 years	age
GRASSES	*Phleum pratense* L.	55.4	22.3	4.5	< 0.001
	Elytrigia repens L.	5.6	20.6	24.6	< 0.001
	Poa pratensis L.	4.4	20.4	24.0	< 0.001
	Festuca pratensis Huds.	16.3	12.3	3.2	< 0.001
	Agrostis capillaris L.	1.0	3.1	8.1	< 0.001
	Deschampsia cespitosa L.	0.6	2.9	6.5	< 0.001
	Poa annua L.	3.6	3.1	2.2	0.29
	Dactylis glomerata L.	0.0	1.9	3.7	0.005
	Alopecurus pratensis L.	1.5	0.7	1.5	0.41
	Bromus inermis	0.4	0.7	1.0	0.77
	Other grasses[1]	0.0	0.0	0.5	< 0.001
	Total	88.9	88.4	79.8	
CLOVER	*Trifolium repens* L.	2.6	1.1	0.8	0.03
	Trifolium pratense L.	3.1	0.6	0.2	0.007
	Total	5.6	1.7	1.0	
HERBS	*Ranunculus repens* L.	1.4	2.8	4.9	0.002
	Taraxacum officinale F.H. Wigg	0.7	2.3	3.8	< 0.001
	Alchemilla spp	0.2	1.1	3.7	< 0.001
	Rumex longifolius DC.	1.5	1.8	1.1	0.50
	Rumex acetosa L.	0.2	0.5	2.7	< 0.001
	Ranunculus acris L.	0.4	0.3	0.8	0.23
	Urtica dioica L.	0.1	0.5	0.8	0.02
	Stellaria media L.	0.5	0.3	0.1	0.009
	Achillea millefolium L.	0.1	0.1	0.6	< 0.001
	Anthriscus sylvestris L.	0.0	0.1	0.3	0.03
	Other herbs	0.4	0.3	0.4	0.50
	Total	5.4	9.9	19.2	

[1]Including grass species, *Carex*, *Juncus* and *Equisetum*.

of *Poa pratensis* is L. partly dependent on the seed mixture, as the species is not included in many silage mixtures. *Elytrigia repens* L. has typically a spotted occurrence in the fields with total dominance in some areas and absence in other areas. Spraying with glyphosate before establishment of grassland is recommended, but the majority of farmers in the mountain districts only spray occasionally. *Elytrigia repens* L. is very competitive and showed high ability to spread in *Phleum pratense*-based grassland.

Even though most of the seed mixtures contains 10% to 15% clover, the clover proportion was very low in our survey. This is probably due to the fertilising practice, where most farmers apply manure in the establishment year and relatively high N doses in the following years. The average content of herbs was highest in the oldest fields at 19%. This proportion probably has small effects both on yield and quality (Haugland, 1995). Herbicides are generally used to control *Rumex longifolius* in this district.

Conclusion

The proportion of sown species declined rapidly with increasing field age in this survey. The persistence of *Festuca pratensis* Huds. was not better than for *Phleum pratense* L.. The low persistence of *Phleum pratense* L. and *Festuca pratensis* Huds. indicates that *Poa pratensis* L. or other long-lasting grass species should be included in seed mixtures for this region when the grassland is intended to last more than three years. The impact of *Elytrigia repens* L. on forage yield and quality should be further examined due to its high occurrence.

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Effect of post-grazing residual pasture height in spring on pasture quality in summer and autumn

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Abstract

An experiment was undertaken in Waikato, New Zealand, to investigate the effect of post-grazing residual pasture height in spring on subsequent pasture quality. Two target post-grazing residual pasture height treatments were established in spring, 4.0 cm (TARGET) and 5.5 cm (HIGH), after which all pastures were grazed to a similar target post-grazing residual height (4.0 - 4.5 cm). HIGH post-grazing residuals in spring resulted in summer and autumn pastures with a lower proportion of perennial ryegrass leaf and pseudostem (0.10; $P < 0.05$) and a higher dead material proportion (+ 0.12; $P < 0.05$). These changes in composition resulted in pastures with a lower organic matter digestibility (- 6.1 g 100 g DM^{-1}; $P < 0.001$) in summer and autumn. These results indicate that achieving low-post grazing residuals in spring reduces the dead material proportion in pastures in summer and autumn, resulting in higher digestibility.

Keywords: grazing, post-grazing residual, pasture, digestibility, botanical composition

Introduction

Current best practise recommendations for dairy farmers in New Zealand are to target a post-grazing sward height of 3.5 - 4.0 cm in spring, but tolerating up to 4.5 cm during reproductive development (McCarthy, 2014). A recent survey of New Zealand dairy farmers indicates that some farmers have lost their focus on attaining control of post-grazing residuals (McCarthy *et al.*, 2014). This may be attributed to increasing use of supplementary feed on NZ dairy farms with substitution (Holmes and Roche, 2007) leading to increased pasture wastage and higher post-grazing residuals. Hypothetically, high post-grazing residual height in spring is likely to have a negative effect on pasture quality and composition at subsequent grazings. Previous work investigating the effects of post-grazing residual height on subsequent pasture characteristics were relatively short-term experiments (e.g. Mayne *et al.*, 1987) or confounded by relatively large differences in pre-grazing pasture mass (e.g. Hoogendorn *et al.*, 1992). The objective of this study was to investigate the effect of post-grazing residuals in spring on pasture botanical and chemical composition in summer and autumn.

Materials and methods

This experiment was undertaken at Scott Farm, DairyNZ Ltd, Hamilton in the Waikato, New Zealand (37°77'S, 175°36'E, 40 m above sea level). The experiment used permanent pastures, predominately perennial ryegrass (0.88; *Lolium perenne* L.) and white clover (*Trifolium repens* L.) and of high digestibility (85.2 g 100 g DM^{-1}). Twenty eight paddocks were allocated to one of two post-grazing residual height treatments: 4.0 cm (TARGET) or 5.5 cm (HIGH) and once allocated were managed independently as two farmlets. Post-grazing residual treatments were applied during spring 2015 (29 August until 16 December) by rotationally grazing paddocks with lactating dairy cows (Period 1). Both treatments had a stocking rate of 3.0 cows ha^{-1} and a similar grazing rotation length of 24 to 28 days. To achieve the targeted difference in post-grazing residual height, cows grazing the HIGH treatment were feed supplemented with up to 3 kg DM Palm Kernel Expeller cow^{-1} day^{-1}. To evaluate the effect of post-grazing residual height in spring on subsequent pasture quality and botanical composition, all paddocks were managed similarly from 17 December 2015 to 31 March 2016 (Period 2) again by rotationally grazing with lactating dairy cows. During Period 2, all paddocks were grazed to a similar target post-grazing residual height (4.0 - 4.5 cm: 8 to 9 clicks on a Rising Plate Meter; RPM). Pre- and post- grazing pasture height was measured directly before and after grazing on three occasions each week using an RPM for the duration of the experiment. Approximately every 14 days, representative samples of pasture were hand-clipped to grazing height from paddocks due to be grazed on each treatment for pasture nutritive value and botanical composition analysis. These pasture samples were oven dried at 60 °C and ground to 1 mm, then analysed for acid detergent fibre (ADF) concentration, neutral detergent fibre (NDF) concentration, crude protein (CP) concentration, organic matter digestibility (OMD) concentration and metabolisable energy (ME) concentration, using near infrared spectrometry (Corson *et al.,* 1999). To measure botanical composition, samples were dissected into perennial ryegrass (split into leaf including pseudostem and reproductive stem), white clover, species and dead material of all species and then oven-dried at 95 °C for 48 h and weighed. Pasture botanical and chemical composition data were analysed for each period separately with mixed models fitted using REML in GenStat 16.0. Treatment was included as a fixed effect and sampling date and paddock within sampling date were included as random effects.

Results and discussion

During Period 1, the average post-grazing residual height was 4.7 cm (SD = 0.6) and 5.6 cm (SD = 0.8) for the TARGET and HIGH treatments, respectively. Pasture botanical and chemical composition were similar for both treatments (Table 1). During Period 2, with the objective of attaining similar post-grazing residual heights on both treatments, average post-grazing residual heights were 4.3 cm (SD = 1.2) and 4.7 cm (SD = 1.3) for the TARGET and HIGH treatments, respectively. Calculated herbage accumulation for the period of the experiment (217 days) was 11,420 kg DM ha^{-1} for the HIGH and 11,835 kg DM ha^{-1} for the TARGET treatments. Consistent with the expected seasonal trends for this location, pasture quality and composition in both treatments deteriorated from spring to summer/autumn. Post-grazing residual treatment in spring had a significant effect on pasture botanical and chemical composition in summer and autumn. Pastures grazed to the HIGH post-grazing residual height in spring contained a higher proportion of dead material (+ 0.12; $P < 0.05$) and a lower proportion (- 0.10; $P < 0.05$) of perennial leaf and pseudostem, in summer and autumn. The higher post-grazing residuals in spring in the HIGH treatment and associated decline in pasture utilisation probably led to greater accumulation of older leaves senescing, resulting in more dead material and lower pasture quality. The effects on pasture

Table 1. Botanical composition of HIGH (5.5 cm) and TARGET (4.0 cm) pasture residuals during spring (Period 1[1]) and summer/autumn (Period 2[1]).

	Period 1				Period 2			
	TARGET	HIGH	sed	Sig[2]	TARGET	HIGH	sed	Sig[2]
Pasture botanical composition								
Ryegrass leaf and pseudostem	0.69	0.68	0.067	ns	0.52	0.42	0.043	*
Ryegrass reproductive stem	0.17	0.21	0.056	ns	0.04	0.03	0.022	ns
White clover	0.03	0.02	0.014	ns	0.07	0.05	0.028	ns
Other species	0.04	0.02	0.029	ns	0.17	0.18	0.044	ns
Dead material	0.07	0.07	0.023	ns	0.20	0.32	0.049	*
Pasture chemical composition								
ADF[3] (g 100 g DM^{-1})	24.5	24.9	0.47	ns	26.7	29.8	0.70	***
NDF[3] (g 100 g DM^{-1})	44.1	44.9	1.02	ns	51.1	55.7	1.29	**
Crude Protein (g 100 g DM^{-1})	19.2	18.5	0.77	ns	18.3	14.8	0.75	***
OMD[3] (g 100 g DM^{-1})	85.7	84.6	0.90	ns	73.4	67.3	1.29	***
ME[3] (MJ[3] kg DM^{-1})	12.6	12.5	0.12	ns	10.8	10.0	0.16	***

[1]See text for definition of Period 1 and 2.

[2]* = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$; ns = not significant.

[3]ADF = Acid detergent fibre; NDF = neutral detergent fibre; OMD = organic matter digestibility; ME = metabolisable energy; MJ = mega joule.

botanicals were supported by changes in pasture chemical composition. HIGH pastures had a greater ADF (3.1 g 100 g DM^{-1}; P < 0.001) and NDF (4.6 g 100 g DM^{-1}; P < 0.01) concentration and lower OMD (6.1 g 100 g DM^{-1}; P < 0.001) concentration compared with TARGET pastures. The decline in pasture quality observed on the HIGH pastures in summer and autumn is consistent with changes in pasture botanical composition as digestibility of dead material is lower than other pasture components (Litherland and Lambert, 2007). Although the post-grazing residual height on the HIGH treatment is not uncommon on farms (McCarthy *et al.*, 2014) and relative differences in grazing intensity in this experiment were less compared with previous work (Stakelum and Dillon, 2007), failure to maintain TARGET post-grazing residuals in spring led to a decline in pasture quality in summer and autumn. This indicates that, if the grazing management objective is to produce pastures of high feed quality for summer and autumn, current recommendations for post-grazing residual height should be followed.

Conclusion

The results from this experiment reaffirm that achieving target post-grazing residuals in spring reduces the proportion of dead material in pastures in summer and autumn, resulting in pastures of higher digestibility.

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Improving the phosphorus use efficiency of perennial forage species to enhance the sustainability of grassland based agriculture

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Abstract

There are environmental concerns associated with the inefficient use of applied nutrients in grassland. Here we describe three phenotyping systems at different scales used to quantify variation in phosphorus (P) uptake and utilisation in the forage legume white clover (*Trifolium repens* L.). This is a first step in the development of varieties that are productive under limited supplies of P.

Keywords: white clover, sustainability, P uptake efficiency, P use efficiency

Introduction

Temperate forage legumes are known to have a relatively high requirement for phosphorus (P) compared with grasses, and recommendations for P fertiliser application on grass-white clover mixtures are higher than for grass-only swards. However, there are limits to global reserves of rock phosphate and it is now considered vital to increase the efficiency with which these reserves are used by crop plants (Veneklaas *et al.*, 2012). It is important to recognise that increasing plant P uptake alone is not sustainable, as this needs to be replaced by further fertiliser inputs; the key to P sustainability lies in improving the efficiency with which plants produce high yields per unit P taken up (P use efficiency: PUE) (Veneklaas *et al.*, 2012). The prerequisite for genetic improvement of nutrient use efficiency is the existence of variation in relevant physiological traits. Here we describe approaches taken to analyse genotypic variation within a white clover genetic mapping family in P uptake and utilisation using three phenotyping systems: performance under steady-state nutrient conditions in flowing solution culture (FSC), computer vision-based phenotyping in the National Plant Phenomics Centre (NPPC), and scoring in a spaced plant experiment in the field.

Materials and methods

The IBERS white clover 'stem nematode mapping family' (Marshall *et al.*, 2012) was used. Stolon cuttings were used to generate clonal replicates, enabling direct comparison between plant responses under different levels of P supply in the different phenotyping platforms. The same genotypes were used in all three systems. Data presented are the means of the clonal replicates.

FSC: Ninety-one genotypes were grown in FSC over 28 days. Three clonal replicates were suspended in tanks supplied with either an optimal P concentration ('high P'), or with 0.2 of this concentration ('low P'). After 28 days, plants were harvested and fresh and dry weights of roots and shoots measured. All herbage and root fractions were analysed for total P concentration to enable uptake (mg P plant^{-1}) and utilisation (g tissue g^{-1} P) efficiencies to be quantified.

NPPC: Computer vision was used to measure plant growth in response to different P treatments in a hortizontal 'gutter' format by placing clonal replicates in ultra-low P compost, with or without Compalox® (a fertiliser product supplying buffered P). Plants were grown for five months and imaged once per month. Plant area information was taken from these images. Manual measurements of different morphometric parameters (e.g. stolon length, leaf spacing and branching pattern) were also made. Finally, total plant biomass was measured and leaf samples were taken to enable P uptake and utilisation efficiencies to be quantified as defined above. These are currently awaiting analysis.

Field: The mapping family genotypes plus control plants of small (cv. AberAce), medium (cv. AberDai) and large leaved (cv. Aran) white clover varieties were grown as spaced plants in two field sites at Gogerddan, Aberystwyth. Six clonal replicates of each genotype were established, and in autumn 2016 three replicates were transplanted into a field site with 'normal' P levels (P index 2) and three into a nearby field site with 'low P' levels (P index 0). Plants were established according to a randomised block design with three replicates. In June 2017, when plants began to flower, their growth and development were evaluated visually on a scale ranging from 0 (poor) to 5 (good).

Results

FSC: There were significant linear relationships in uptake and utilisation efficiencies for genotypes' responses to high and low P ($P < 0.001$ in both), and substantial genotypic variation within this mapping family (Figure 1). P uptake efficiency in almost all genotypes was greater in the high P treatment; however, PUE was greater under low P in the majority of genotypes.

NPPC: The population showed considerable variation in response to P treatment. A subset of genotypes has been chosen for a more detailed growth study i.e. those in which the growth response differed substantially under the two P treatments.

Field: Analysis of growth scores (Figure 2) showed that growth was generally greater under 'normal' P. There were some mapping family genotypes with a greater growth score under 'low P' than under 'normal' P, but these tended to have relatively low overall growth scores (< 2.5).

Discussion

The mapping family was originally developed to study susceptibility to stem nematode infection, but the variation in PUE among its component genotypes makes it particularly useful for the analysis of this trait. An objective of these experiments was to determine if the components of PUE apparent in FSC are similarly exhibited when plants are grown in the field. Caradus (1994) proposed that successful identification of genotypes adapted to low P soils is more likely to be made in the field rather than in

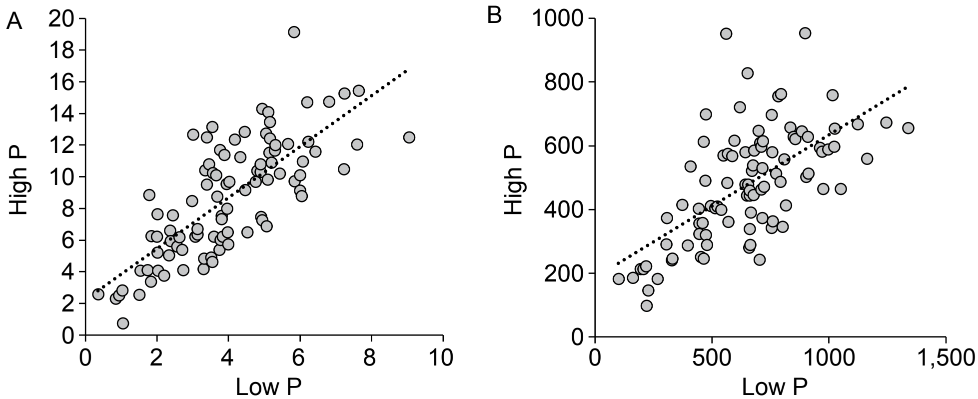

Figure 1. (A) P uptake (mg P plant^{-1}) and (B) P utilisation efficiency (g tissue g P^{-1}) of 91 genotypes of a white clover mapping family under high and low P supply in FSC over 28 days. Each point represents the mean of 3 replicates. Dotted lines are best-fit linear regressions. R^2 for (A) = 0.57; (B) = 0.40.

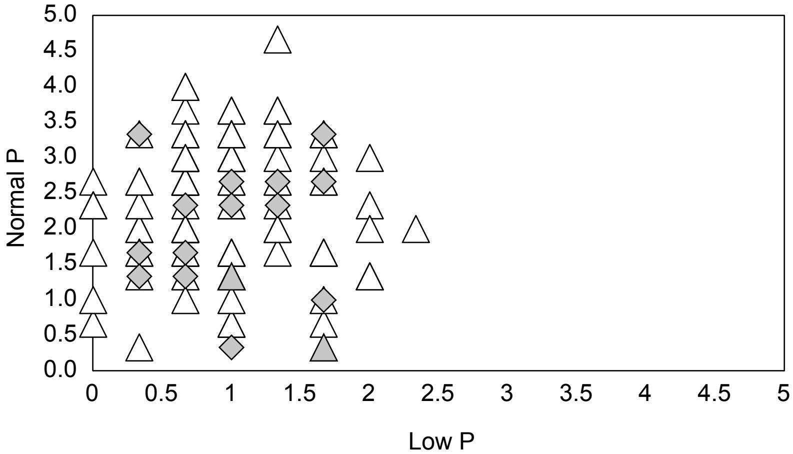

Figure 2. Growth scores of genotypes of the white clover mapping family, mapping family parents and control varieties grown as spaced plants in field plots under 'low' and 'normal' P conditions. Each data point is a mean of three replicate plants.Solid triangles are the mapping family parents, open triangles are mapping family genotypes, solid diamonds are control variety genotypes.

artificial growth systems, as screening under controlled conditions focuses on a single limiting factor with the assumption that it is important in the field. For example, FSC focuses solely on the nutrient uptake characteristics of root systems under steady-state nutrient supply, whilst disregarding the important role of root system architecture in nutrient capture.

Conclusion

All systems highlighted considerable variation in the growth of mapping family genotypes in response to P supply, providing a first step in the development of white clover varieties with improved PUE.

Acknowledgements

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Long term influence of botanical composition of alpine pastures on cow milk production

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Abstract

Subalpine pastures in the Carpathian region of Romania were evaluated using the milk production response of dairy cows following three different treatments (application of fertiliser; application of fertiliser, lime and paddocking; or fertiliser and lime application, paddocking and reseeding). This paper presents the evolution of the botanical composition of the pastures over a period of 20 years (1996 - 2015), the chemical analyses of the fodder and its influence on cow milk production in an 85 - 90 day grazing season. This research shows that the different treatments had an incremental effect on milk production through their effect on the sward botanical composition. Botanical evaluation can be used instead of fodder analyses as a means of evaluating the milk production potential of such pastures.

Keywords: *Nardus stricta*, improvement, botanic composition, grazing, milk

Introduction

The subalpine pastures of the Romanian Carpathians, situated between 1,800 to 2,200 m above sea level in the south and at 1,600 to 2,000 m in the north, are widely invaded by the *Nardus stricta* species. To improve these degraded grasslands, experiments evaluating the application of lime and chemical fertilisers, paddocking and reseeding have been carried out (Puşcaru *et al.*, 1956; Bărbulescu and Motcă, 1983; Maruşca and Frame, 2003; etc.). The present paper reports on the role of liming and reseeding, in conditions of normal chemical and paddocking fertilisation, on botanical composition, pastoral value (PV) and cow milk production in each region.

Materials and methods

The experiments were started in 1995 in the Mountain Pasture Research Base from Bucegi Plateau, located at 1,800 m altitude on the sub-alpine juniper tree (*Pinus mugo*) floor, in pastures infested with 40 to 60% *Nardus stricta*. Three treatments were chosen:

- A - Chemical fertilisation with N 150 kg ha^{-1} + 50 kg ha^{-1} P_2O_5 + 50 kg ha^{-1} K_2O for three consecutive years, followed by paddocking, a cow 6^{-1} square meters (sq. m.) and with additional application of 100 kg ha^{-1} P_2O_5 in 2010.
- B - Liming with approximately 7.5 t ha^{-1} CaO, (1995), to correct the soil acidity, followed by the same doses of NPK chemical fertilisers and paddocking as per treatment A.
- C - Reseeding following a herbicide application of Glyphosate (Roundup 5 l ha^{-1}, 1995), tilling to a depth of 10 - 12 cm, sowing with a mixture of *Phleum pratense* (40%), *Festuca pratensis* (25%), *Lolium perenne* (5%), *Trifolium hybridum* (15%) and *Lotus corniculatus* (15%) species, preceded by liming as per treatment B, followed by fertilisation and paddocking, as per treatments A and B.

The size of each experimental plot was 7,500 sq. m., which were intensively grazed for 85 - 90 days per year, by three Schwyz brown cows, fed exclusively with grass.

Three metal cages (2 m^2 each) were placed in each treatment area. Samples were taken to determine DM production, chemical analysis and partial botanical composition. The KLAPP-ELEMBERG percentage method was used to determine the pastoral value (PV) of treatment swards.

Results and discussion

Over a 20 period (1996 - 2015), the botanical composition of the pastures were recorded annually by the main author of the paper (Table 1). Botanical results have highlighted the beneficial effect of liming and reseeding on better fodder species such as *Agrostis capillaris*, *Poa pratensis* and *Trifolium repens* from the indigenous flora, which together with introduced species such as *Phleum pratense* and *Festuca pratensis* have significantly increased PV.

The dynamic evolution of PV and milk production are shown in Table 2. The PV ranges between 58 and 87, are more constant in Treatment B with liming of the permanent grassland. Milk production varied from 2291 to 4709 l ha^{-1}, depending on the applied treatments.

Between PV and dairy production over 20 years, there is a statistically positive correlation coefficient of 5%, respectively for a PV unit, milk production increases by 51.24 l ha^{-1} (Figure 1).

This synthetic index can be applied to all subalpine pastures in the Carpathians once accurate botanical composition and PVs are determined.

Table 1. Influence of liming and reseeding on botanical composition and Pastoral Value.

Species	I.F.*	Medium value 1996 - 2015				Differences	
		A	B	C	B – A	C – B	C – A
Spontaneous							
Agrostis capillaris	7	10	21	28	+11	+7	+18
Agrostis rupestris	5	6	1	1	-5	0	-5
Deschampsia caespitosa	0	4	2	4	-2	+2	0
Deschampsia flexuosa	4	8	1	+	-8	-1	-9
Festuca nigrescens	7	18	17	4	-1	-13	-14
Nardus stricta	0	4	+	-	-4	- +	-4
Phleum alpinum	6	7	3	1	-4	-2	-6
Poa media	5	15	6	1	-9	-5	-14
Poa pratensis	8	4	13	16	+9	+3	+12
Trifolium repens	8	8	14	10	+6	-4	+2
Ligusticum mutellina	7	4	2	+	-2	-2	-4
Polygonum bistorta	5	6	12	1	+6	-11	-5
Potentilla ternata	4	2	1	+	-1	-1	-2
Taraxacum officinale	7	1	2	1	+1	-1	0
Other indigenous species	4	3	5	7	+2	+2	+5
Reseeded							
Festuca pratensis	9	-	-	11	X	X	X
Lolium perenne	9	-	-	+	X	X	X
Phleum pratense	9	-	-	15	X	X	X
Pastoral value (PV)	X	62	72	80	+10	+8	+18
Liming effect (B-A)(%)	X	100	116	X	+16	X	X
Sowing effect (C-B) (%)	X	X	100	111	X	+11	X
Liming + sown (C-A)(%)	X	100	X	129	X	X	+29

*Index of fodder quality.

Table 2. Evolution of pastoral value and cow performance depending on liming and reseeding.

Specification	Variant	1996 - 2000	2001 - 2005	2006 - 2010	2011 - 2015	Medium value
Pastoral value (PV)	A	58	62	58	68	62
	B	71	73	72	72	72
	C	87	83	77	74	80
Liming effect (%)	B – A	122	118	124	106	116
Reseeding effect(%)	C – B	123	114	107	103	111
Liming + Reseeding (%)	C – A	150	134	133	114	129
Milk production (l ha^{-1})	A	3,652	2,291	3,700	3,254	3,367
	B	4,417	3,259	4,073	3,700	3,862
	C	4,709	4,617	4,485	3,472	4,320
	B – A	121	142	110	114	115
	C – B	107	140	110	94	112
	C – A	129	202	121	107	128

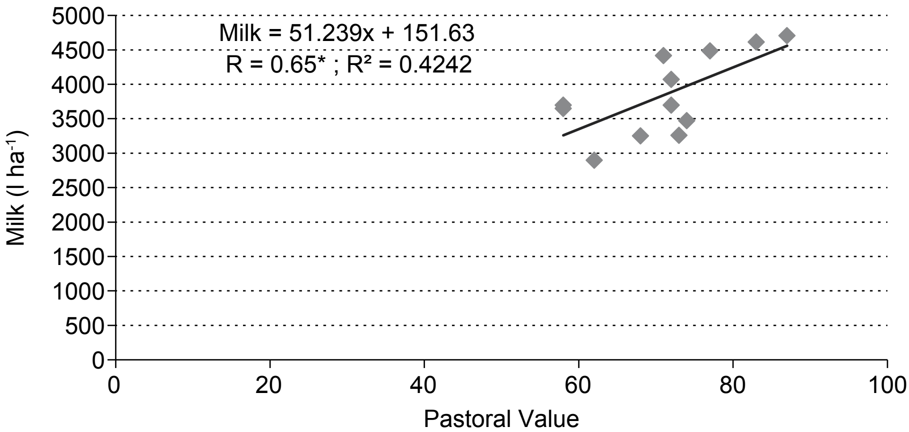

Figure 1. Correlation between pastoral value (PV units) and milk production (l ha-1).

Conclusion

The milk production potential of subalpine pastures in the Carpathian mountains can be predicted by determining their PV, using a coefficient of 51.24 in the conditions of a rotational grazing.

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Prediction of fatty acid content and composition of forages in the new INRA feed tables

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Abstract

Forages may contribute to the nutritional value of milk and meat through their content and composition in fatty acids (FA). To optimise a ruminant diet for a target milk or meat FA composition, we need to know the FA content and composition of feedstuffs. However, no detailed FA composition of forages is available in feed tables. The objective of this study was to develop predictive models of FA content and composition of forages, from a database of published studies post-dated 1970. Models were developed for fresh forages, for estimating total FA content and FA composition from crude protein (CP) content and from total FA content, respectively. For conserved forages, total FA content and composition were estimated from the corresponding fresh forage using models integrating the effects of conservation and harvest conditions. Models were also established to estimate their FA content and profile from their CP content when the laboratory analysis is performed on conserved forages. Overall, these models enable the estimation of FA content and composition for different types of forages and were applied to complete the characterisation of forages in the new INRA feed tables.

Keywords: fatty acid, forage, feed table, predictive equation

Introduction

Forages represent a major part of ruminant diets and can sometimes contain significant amounts of fat and polyunsaturated fatty acid (FA): fresh grass contains 10-30 g kg^{-1} DM of total FA, composed of 35 - 70 g 100 g of linolenic acid (18:3). Diets based on pasture or grass silage can thus improve the nutritional quality of milk and meat (Dewhurst *et al.*, 2006; Scollan *et al.*, 2006). To optimise diet composition for target milk or meat FA composition, the FA content and composition of dietary feedstuffs is required. Currently, FA content and composition of concentrate feedstuffs are available in INRA feed tables (Sauvant *et al.*, 2004). However, except for the Nordic countries (NorFor, 2011), no feed table provides FA compositions for forages. Numerous factors influence the FA content and composition in forages: species, stage of vegetation, conservation and nitrogen fertilisation. Glasser *et al.* (2013), quantified and compared by meta-analysis the effects of these different factors. The main factor influencing FA composition was vegetation stage at harvest: total FA content and 18:3 decrease as plant maturity advances. The second factor was wilting which decreases the content of 18:3 by 7 to 14% in bad wilting conditions. The objective of this work was to establish by meta-analysis, models to predict the total FA content of forages and their composition in major FA in order to include these values into the INRA feed tables of forages.

Materials and methods

The database built by Glasser *et al.* (2013), was used to establish the predictive equation of FA content and composition. This database (officially filed as IDDN. FR. 001.510026.000. R.P.2011.000.10300) included publications dated post-1970 and reporting the chemical composition of forages, especially the following measurements: FA composition, total FA or fat content of the forages. Briefly, the main species in the database were for grass: ryegrass, cocksfoot, timothy and fescue and for legumes: white clover, red clover and lucerne. Permanent grasslands, temporary grasslands and associations were gathered together in a 'Mixtures' category. Included in the database were 53% of fresh forages, 28% grass silages, 12%

hay and 7% maize silages. There were not enough data for straw, brassica species, sorghum, and whole crop cereals to develop predictive equations. Average values were calculated from published data for these forages and provided in the feed tables. Predictive equations were established for total FA content (expressed in g kg^{-1} DM) and for the composition in 16:0, 18:0, 18:1, 18:2 and 18:3 (in g 100g total FA). Potential predictors for the equations were plant species, forage type, conservation method and vegetative stage. Accounting for the effect of vegetation stage was difficult as information reported in the publications was very diverse (harvest date, regrowth interval, number of cuts, etc.). Thus, relationships between vegetative stage and some chemical characteristics were tested to identify one chemical criterion reflecting the effect of vegetative stage. Mixed procedure of SAS was used to develop equations. The factor 'experiment' was considered as a random effect.

Results and discussion

Crude protein (CP) content was closely related (r = 0.79) to total FA content, this is explained by the same location of CP and FA in the plants in leaves rather than in stems (Boufaïed *et al.*, 2003). Consequently, we developed equations to predict FA content and composition from CP content in order to take into account the effect of vegetation stage and with fixed effects to include effects of the other factors, such as botanical family and conservation method.

For fresh forages, a predictive equation was established, by forage type, to calculate the total FA content (g kg^{-1} DM) from CP content (g kg^{-1} DM):

$$FA = 1.78 + 0.105 \times CP + \Delta_1 \ (N_{study} = 20, N_{data} = 50, RMSE = 2.6\ g\ kg^{-1}\ DM),$$

with $\Delta_1 = 0$ for mixtures, $\Delta_1 = +5.45$ for grasses, and $\Delta_1 = -2.12$ for legumes.

The FA composition of fresh forages (i.e. proportion of 16:0, 18:0, 18:1, 18:2 and 18:3) was then estimated from their total FA content and considering the different forage types (Table 1). At similar total FA content, grasses contain higher 18:3 content than legumes. Specific coefficients were developed for lucerne as it contains more 16:0 and less 18:3 than other legumes.

In the INRA feed tables, FA content and composition of conserved forages were estimated from values of the corresponding fresh forages using equations integrating the effects of conservation method and harvest conditions. These equations are detailed in Glasser *et al.* (2013); they were used for all legumes except lucerne, as data showed a stronger decrease in FA content and 18:3 for lucerne with conservation than for other legumes. To predict FA content and composition of conserved forages from laboratory chemical analysis, direct equations were developed to predict FA content and composition of conserved forages from their CP content, the conservation method (silage, hay) and the forage type. These equations were used for completing lucerne values in the INRA feed table.

Table 1. Equations used to predict the FA composition (g 100 g total FA) of fresh forages from total FA content (g kg^{-1} DM).

Equations	Fixed coefficients (Δ_2 values)				RMSE	N_{data}
	mixtures	grasses	legumes	lucerne		
$16{:}0 = 23.24 - 0.445 \times FA + 0.005 \times FA^2 + \Delta_2$	0	+ 1.44	+ 1.60	+ 5.65	1.52	143
$18{:}0 = 2.92 - 0.027 \times FA + \Delta_2$	0	- 0.57	+ 0.60	+ 1.64	0.56	118
$18{:}1 = 5.23 - 0.052 \times FA + \Delta_2$	0	- 1.19	- 0.25	- 0.68	0.91	132
$18{:}2 = 20.59 - 0.186 \times FA + \Delta_2$	0	- 1.81	+ 2.04	+ 1.09	1.78	161
$18{:}3 = 35.47 + 1.107 \times FA - 0.012 \times FA^2 + \Delta_2$	0	+ 3.44	- 3.10	- 6.71	3.48	161

Table 2. Values for Δ_3 according to forage type and conservation method in the direct predictive equations of FA content and composition of conserved forages.

	Mixtures		Grasses		Legumes	
	silage	hay	silage	hay	silage	hay
Total FA	+ 1.40	- 2.81	+ 3.02	+ 1.95	- 0.70	- 3.98
16:0	+ 1.41	+ 5.26	+ 1.64	+ 1.99	+ 1.75	+ 7.40
18:1	- 0.25	+ 0.37	- 0.13	- 1.05	+ 0.44	+ 2.11
18:2	+ 0.86	+ 1.01	+ 0.14	- 0.11	+ 4.08	+ 2.99
18:3	- 2.78	- 7.15	- 0.80	- 1.30	- 8.15	- 24.04

$FA = 5.68 + 0.083 \times CP + \Delta_3$, ($N_{study} = 48$, $N_{data} = 146$, RMSE = 2.4 g kg^{-1} DM),
$16{:}0 = 18.90 - 0.011 \times CP + \Delta_3$, ($N_{study} = 67$, $N_{data} = 176$, RMSE = 1.89 g 100 g total FA),
$18{:}1 = 4.64 - 0.006 \times CP + \Delta_3$, ($N_{study} = 62$, $N_{data} = 160$, RMSE = 0.71 g 100 g total FA),
$18{:}2 = 18.92 - 0.020 \times CP + \Delta_3$, ($N_{study} = 70$, $N_{data} = 188$, RMSE = 1.42 g 100 g total FA),
$18{:}3 = 42.18 + 0.057 \times CP + \Delta_3$, ($N_{study} = 71$, $N_{data} = 189$, RMSE = 4.31 g 100 g total FA).

Proportion in 18:0 did not vary with CP content ($P = 0.15$, $N_{data} = 118$), but was affected by forage type and conservation. Thus, mean values were provided in the feed tables. Data available for corn silage did not allow the development of predictive equations for FA content and composition. Average values for total FA, 16:0, 18:0, 18:1, 18:2 and 18:3 were added in the feed table.

Conclusion

These equations enable the prediction of FA content and composition for the main forage type from their CP content. Despite the heterogeneity of available data, the equations account for the effect of the most important factors (forage type, vegetative stage and conservation). Despite the large total number of data, once the database was split among the different factors, only few data remained for some factors. This is why the factor 'forage type' is used in the equations rather than 'species'. These equations were applied to complete the INRA feed table for forages (Baumont *et al.*, 2018). The American (NRC, 2001) and Dutch (CVB, 2011) systems only provide the fat content of forages. In NorFor tables, FA composition are available, but values are based on averaged values from three publications and do not include the effects of the different factors through predictive equations. The new INRA feed tables (Baumont *et al.*, 2018) are the only feed tables to propose such detailed FA characterisation for forages.

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Comparison of pasture-based feeding systems and a total mixed ration feeding system on dairy cow milk production

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Abstract

Diet is the one of the main determinants of milk and milk solids (MS) yield. A well-balanced total mixed ration (TMR) offers the greatest potential to maximise milk production per cow. The ability to alter the diet to suit the cows' requirements (age, stage of lactation, etc.) gives TMR diets an advantage over grass-based systems in terms of attaining maximum output per cow. Previous research has shown the potential benefits of incorporating white clover (*Trifolium repens* L.) into perennial ryegrass (*Lolium perenne* L.) swards. The objective of this experiment was to examine the effect of feeding system on dairy cow milk and MS yield. The experiment consisted of three treatments – TMR (grass silage, maize silage, concentrate), grazed grass-only receiving 250 kg nitrogen (N) ha^{-1} (GO) and grazed grass-white clover receiving 250 kg N ha^{-1} (GC) and was conducted over two full lactations. Total concentrate fed per lactation was 245 kg cow^{-1} for GO and GC, and 2,593 kg cow^{-1} for TMR. There was no effect of grazing treatment on cumulative herbage production (13,896 kg DM ha^{-1}). The TMR treatment had the highest cumulative milk and MS yield and GO had the lowest. Incorporating white clover into the grass sward significantly increased (P < 0.05) milk production (+ 588 kg milk and + 41 kg MS cow^{-1}) compared to GO.

Keywords: white clover, grass, total mixed ration, milk production

Introduction

In milk production systems, feed quality is the single greatest determinant of milk production (Wilkins, 2004). In grass-based systems the quality of the diet is variable and milk production per cow is often lower than when feeding total mixed ration (TMR) diets (Kolver and Muller, 1998; Bargo and Muller, 2002). These authors suggest that, in grazing conditions, energy intake is the most limiting factor for milk production (Kolver and Muller, 1998; Bargo and Muller, 2003). There is renewed interest in incorporating white clover (*Trifolium repens* L.; clover) into grass-based milk production systems in Ireland due to its ability to fix nitrogen (N), improve herbage quality and utilisation and increase milk production (Egan *et al*., 2017). The objective of this experiment was to examine the effect of the feeding system on dairy cow milk yield (MY) and milk solids (MS) yield by comparing three feeding systems: TMR, grazed grass-only (GO) and grazed grass-clover (GC).

Materials and methods

A full lactation farm systems experiment (February to November) was undertaken at Teagasc Moorepark, Fermoy, Co. Cork, Ireland in 2015 and 2016. The experiment had three treatments: TMR (grass silage, maize silage, concentrate), GO receiving 250 kg N ha^{-1} and GC receiving 250 kg N ha^{-1}. The TMR diet consisted of, on a DM basis, 7.15 kg grass silage, 7.15 kg maize silage and 8.3 kg concentrates cow^{-1}. The GO swards consisted of perennial ryegrass (*Lolium perenne* L.) consisting of a 50:50 mix of Astonenergy and Tyrella sown at a rate of 27.2 kg ha^{-1} in 2012 and 2013. The GC swards had the same perennial ryegrass mix as GO plus a 50:50 mix of white clover cultivars Chieftain and Crusader sown at a rate of 5 kg ha^{-1}, also sown in 2012 and 2013. The GO and GC treatments received 245 kg of concentrate cow^{-1} per lactation, fed in February, March and November, and the TMR treatment received 2,592 kg concentrate cow^{-1} per lactation. The grazing treatments (GO and GC) were stocked at 2.74 cows ha^{-1} in a closed farm system (i.e. the farmlet provided all grazed herbage and silage for the animals in the treatment). Both grazing groups were rotationally grazed, achieving 8.3 rotations per year. In February of each year, 54 spring calving Friesian and Friesian × Jersey dairy cows were blocked on calving date (16 Feb ± 16.9 days), breed, parity (2.86 ± 1.84), pre-experimental MY (MY for first 2 weeks of lactation; 24.0 ± 4.8 kg) and pre-experimental MS (2.02 ± 0.43 kg) yield (as for MY), and randomly allocated to one of the three treatments (n = 18). Cows remained in their treatment groups for the entire lactation. Swards were rotationally grazed to a target post-grazing sward height of 4 cm. Sward clover content was measured in each GC paddock prior to grazing as described by Egan *et al.* (2017). Cows on the TMR treatment were housed on cubicles with rubber mats and fed at 08:30 h each day using a Keenan diet feeder (Keenan, Borris, Carlow, Ireland). Cows were fed *ad-libitum* to approximately 10% refusal levels via electronically controlled Griffith Elder Mealmaster individual feed bins (Griffith Elder and Company Ltd, Suffolk, England). Milking took place at 07:30 and 15:30 h daily. Milk yield was measured daily and milk composition (fat, protein, lactose) was measured weekly. Data were analysed using PROC MIXED in SAS with terms for treatment, time and associated interactions. Fixed terms were treatment and week or rotation, and random terms were cow and paddock.

Results and discussion

The TMR treatment had significantly greater ($P < 0.05$) daily MY and MS yield compared with the GC and GO treatments (Table 1), most likely due to the higher and more consistent quality of the TMR diet compared with the herbage diets (Kolver and Muller, 1998; Bargo *et al.,* 2002). Similar to Egan *et al.* (2017), GC treatments had significantly greater ($P < 0.01$) MY and MS compared with GO treatments, particularly from June until the end of lactation (Figure 1) when sward clover content increases, resulting in increased herbage quality. Cumulative milk yield was significantly less on the GO treatment compared with GC and TMR. Clover inclusion in the diet significantly increased cumulative MY (+ 588 kg) and MS yield (+ 41 kg) per cow compared with GO. This increase in MS yield from the GC treatment can be attributed to an increase in MY rather than from increased milk constituents (Table 1). Both the GO and GC treatments had significantly greater ($P < 0.05$) milk protein concentrations than the TMR treatment. There was no significant difference in milk fat concentrations between the groups. There was no significant difference in cumulative herbage production between the two grazing treatments; GO and GC treatments grew 13,840 and 13,953 kg DM ha^{-1}, respectively. The average annual sward clover content of the GC treatment was 24%.

Table 1. Daily and cumulative milk production from cows grazing grass-only receiving 250 kg N ha^{-1} (GO), cows grazing grass-clover receiving 250 kg N ha^{-1} (GC), and cows fed on a total mixed ration diet indoors (TMR) over two full lactations (2015 and 2016).

	GO	GC	TMR	SEM[1]	TRT[2]
Milk yield (kg cow^{-1} day^{-1})	22.5^a	24.4^b	26.4^c	0.66	< 0.05
Milk solids yield (kg cow^{-1} day^{-1})	1.83^a	1.94^b	2.08^c	0.035	< 0.01
Milk fat content (g kg^{-1})	46.1^a	45.3^a	46.0^a	0.08	NS
Milk protein (g kg^{-1})	35.4^a	35.0^a	33.3^b	0.03	< 0.05
Cumulative milk yield (kg cow^{-1})	6195^a	6783^b	7234^b	167.0	< 0.05
Cumulative milk solids yield (kg cow^{-1})	498^a	539^b	570^c	10.9	< 0.001

Treatments with the same letter in a row are not significantly different to each other; [1]SEM=Standard Error of the Mean; [2]TRT=Treatment

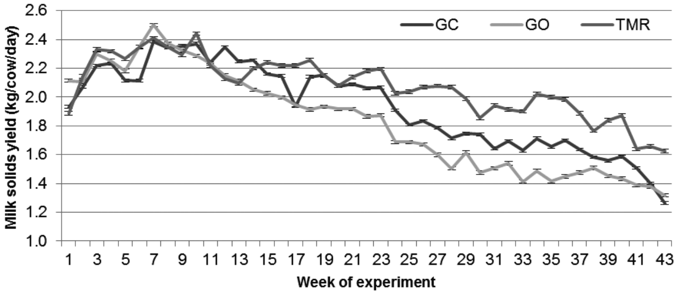

Figure 1. Daily milk solids yield (kg MS cow^{-1} day^{-1}) of cows grazing grass-only receiving 250 kg N ha^{-1} (GO), cows grazing grass-clover receiving 250 kg N ha^{-1} (GC) and cows fed on a total mixed ration diet indoors (TMR) over two full lactations (2015 and 2016).

Conclusion

Clover inclusion did not increase total sward herbage production. Feed system had a significant effect on milk and MS yield; the TMR treatment had greater milk production than both of the grazing groups. Clover inclusion in the sward significantly increased milk and milk solids yield per cow compared to GO swards.

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The effect of nitrogen on herbage production and sward white clover content in frequently grazed swards

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Abstract

Previous research has shown that both nitrogen (N) rate and perennial ryegrass (*Lolium perenne* L.) ploidy can have a significant effect on herbage production and white clover (*Trifolium repens* L.) content in grass-clover swards. The objective of this study was to determine the effect of ploidy and N fertiliser application rate on sward clover content and herbage production under frequent, tight grazing. Plots were grazed up to eight times each year for three years. The experiment had a 2 × 2 × 5 factorial design with four replicates. There were two sward types (grass-only, grass-clover), two perennial ryegrass ploidies (diploid, tetraploid) and five N application rates (0, 60, 120, 180, 240 kg N ha^{-1}). There was a significant effect (P < 0.05) of year on herbage production, clover proportion, stolon mass and tiller density. Ploidy had no significant effect on herbage dry matter (DM) production or sward clover content. White clover inclusion increased herbage production on the 0, 60,120,180 kg N ha^{-1} treatments compared with grass-only. Herbage production was significantly lower (P < 0.05) on grass-only and grass-clover swards receiving no N compared with those receiving N fertiliser. Sward clover content was significantly greater (P < 0.05) on the treatment receiving no N compared with all other clover N treatments.

Keywords: nitrogen, herbage production, white clover, grazing

Introduction

Previous research has shown that perennial ryegrass (*Lolium perenne* L.) ploidy can have a significant effect on sward white clover (*Trifolium repens* L.; clover) content (Gooding *et al.*, 1996). Tetraploid swards have been shown to have greater clover contents compared with diploid swards. Nitrogen (N) fertiliser is one of the biggest inputs to pasture-based systems. Intensive grass-based dairy production systems in Ireland rely on the use of inorganic N to support high levels of herbage dry matter (DM) production and milk output (Wall *et al.*, 2014). However, there is growing concern that excessive N losses can be damaging to the environment (Treacy *et al.*, 2008). The implementation of the Water Framework Directive (2003) and the Nitrates Directive (2009) have placed increased pressure on farmers to farm in a more environmentally friendly manner, including limiting the amount of inorganic N that can be applied. This legislation, along with fluctuations in the price of inorganic N (Kenkel and Fitzwalter, 2015) has increased the focus on N use efficiency at farm level, as well as resulting in farmers seeking alternative sources of N. One alternative source of N is N fixation via clover (Boller and Nösberger, 1987). As well as fixing N, incorporating clover into grass swards can improve herbage feed quality, dairy cow DM intake and animal performance (Harris *et al.*, 1997). The objective of this experiment was to compare the effect of N fertiliser application rate and perennial ryegrass ploidy on herbage DM production and sward clover content in frequently grazed swards.

Materials and methods

This experiment was undertaken at Teagasc, Moorepark, Fermoy Co. Cork, Ireland (520 9' N; 80 16' W). The soil type was a free-draining, acid brown earth of sandy loam to loam texture. Eighty grazing plots (8 × 3 m) were established in 2013. The experiment had a 2 × 2 × 5 factorial design with four replicates. Treatments consisted of grass-only and grass-clover swards receiving one of five N treatments

(0, 60, 120, 180, 240 kg N ha^{-1}; hereafter referred to N1, N2, N3, N4, N5, respectively). The swards consisted of either tetraploid (Kintyre) or diploid (AberChoice) perennial ryegrass cultivars sown with or without clover. Plots were randomly assigned to their treatment. Plots were grazed seven - eight times per year between mid-February and mid-October by lactating dairy cows. Measurements were taken from 2014 to 2016, inclusive. Immediately prior to each grazing, pre-grazing herbage mass was determined by harvesting a strip of known length and 1.2 m wide in each plot using an Etesia mower (Etesia UK., Ltd., Warwick, UK). The harvested material was weighed, length of cut measured and DM content was estimated by drying a 100 g sub-sample at 90 °C for 15 h. Post-grazing sward height (cm) was measured on each plot using a rising plate meter (Jenquip, Feilding, New Zealand) immediately after grazing. Sward clover content was determined four - five times per year by removing random grab samples of herbage from each plot using a Gardena hand shears (Gardena International GmbH, Ulm, Germany), cutting to 4 cm. A sub-sample (approx. 70 g) was separated into clover and grass fractions and dried at 90 °C for 15 h to determine the DM proportion of grass and clover in the sward. Stolon mass and tiller density were measured in March, July and October by removing two 10 cm^2 turves from each plot. Perennial ryegrass and weed grass tillers and dicotyledonous plants were counted. Stolons leaves and roots were removed and washed and dried at 40 °C for 48 h to determine stolon mass (g DM m^{-2}) as described by Harris (1994). Data were analysed using linear mixed models that allowed for repeated measurements using the MIXED procedure in SAS (2003). The model included N application rate, sward type, rotation, year and ploidy as repeated measures across years.

Results and discussion

Clover inclusion in the sward increased herbage DM production in all treatments compared to grass-only, except for the N5 treatment (Table 1). Nitrogen rate had a significant effect on average herbage DM production. The N3, N4 and N5 swards had significantly greater ($P < 0.05$) herbage DM production than the N1 swards. There was no effect of ploidy on sward clover content. Nitrogen rate had a significant ($P < 0.05$) effect on sward clover content; increasing N application rate led to a decrease in sward clover content, with the exception of the grass-clover N5 treatment. The grass-clover N1 treatment had, on average, 9.5% greater clover content that those receiving N. Ploidy had a significant effect ($P < 0.001$) on tiller density; diploid swards had a greater tiller density (4,373 tillers m^{-2}) compared with tetraploid swards (3,585 tillers m^{-2}). Sward type did not have a significant effect on tiller density. Year had a significant effect ($P < 0.001$) on stolon mass which decreased from year one to year three of the study.

Table 1. Effect of nitrogen (N) application rate on herbage production and sward structural characteristics.

		N application rate (kg N ha^{-1})					S.E.	N rate	Sward type	Ploidy	Year
		0	60	120	180	240					
Herbage production	grass only	7,178	9,012	9,995	10,395	11,153	360.6	***	*	NS	***
(kg DM ha^{-1})	grass clover	8,346	9,510	10,618	10,540	11,098					
Pre-grazing herbage mass	grass only	10,10	1,260	1,394	1,449	1,552	49.44	***	NS	NS	***
(kg DM ha^{-1})	grass clover	11,82	1,328	1,479	1,469	1,545					
Post-grazing sward height	grass only	3.58	3.65	3.69	3.74	3.79	0.092	*	*	NS	***
(cm)	grass clover	3.24	3.47	3.58	3.53	3.68					
Clover content	grass only	-	-	-	-	-	2.41	*	-	NS	***
(g kg^{-1})	grass clover	33	25.6	23.2	17.6	25.8					
Stolon mass	grass only	-	-	-	-	-	6.84	*	***	NS	***
(g m^{-2})	grass clover	31.5	32.2	10.7	14.1	15.4					
Tiller density	grass only	3,676	4,316	4,116	4,233	4,369	274.4	NS	NS	*	NS
(tillers m^{-2})	grass clover	3,502	4,038	3,907	3,736	3,897					

S.E. = standard error of the mean; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$; NS = not significant.

Ploidy had no effect on stolon mass. Nitrogen rate had a significant effect ($P < 0.05$) on stolon mass. The grass-clover N1 and grass-clover N2 swards had greater stolon mass than the grass-clover N3, N4 and N5 swards. Grass-clover swards had significantly lower post-grazing sward height (3.50 cm) compared to the grass-only swards (3.69 cm). Nitrogen rate had a significant effect ($P < 0.05$) on post-grazing sward height. The grass-clover N1, N2, N3 and N4 swards had lower post-grazing sward heights than their grass-only counterparts. Ploidy had no effect on post-grazing sward height. White clover inclusion led to improved herbage DM production and utilisation while ploidy had no effect on sward clover content.

Conclusion

White clover inclusion in the sward led to improved grazing efficiency through lower post grazing residuals while also increasing herbage DM production compared with grass-only at all N levels except N5. Herbage DM production increased with increasing N application rate. Ploidy had no effect on herbage DM production or sward clover content.

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Perennial ryegrass cultivar: effect on herbage dry matter production and sward nutritive value

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Abstract

Within grass-based production systems herbage DM production, post-grazing sward height and sward nutritive value have an important impact on performance. Perennial ryegrass (*Lolium perenne* L.) cultivar can be one of the main factors influencing these variables. The aim of this study was to assess the performance of eight perennial ryegrass cultivars (four tetraploid (Astonenergy, Kintyre, Twymax and Dunluce) and four diploid (Tyrella, Aberchoice, Drumbo and Glenveagh)) within a large-scale dairy systems experiment over three grazing seasons. There were four grazing treatments (tetraploid only, diploid only, tetraploid + white clover and diploid + white clover), stocked at 2.75 cows ha^{-1} with treatments receiving 250 kg nitrogen ha^{-1} annually. Twenty blocks of four paddocks each were created and within these blocks the eight cultivars were sown as monocultures with and without white clover five times, thereby, creating a separate farmlet of 20 paddocks for each treatment. Cultivar had a significant effect on grazing, silage and total herbage DM production, post-grazing sward height and on sward nutritive value.

Keywords: perennial ryegrass cultivar, white clover, grazing

Introduction

The production and utilisation of increased quantities grazed grass has the potential to significantly reduce input costs and increase profitability of dairy farms (Dillon *et al.,* 2008). Perennial ryegrass (*Lolium perenne* L.; PRG) is the basis for temperate grazing systems in Europe and PRG cultivar has been shown to influence grazed herbage DM production, sward nutritive value and sward density on commercial dairy farms in Ireland (Byrne *et al.,* 2017). Perennial ryegrass cultivar has also been shown to influence milk production from grazing dairy cows (Wims *et al.,* 2013). There is renewed interest in the use of forage legumes and white clover (*Trifolium repens* L.; WC) in particular, in grazing systems due to the potential for increased herbage and animal production (Lüscher *et al.,* 2014). The objective of this study was to assess the performance of eight PRG cultivars (four tetraploid and four diploid) sown with and without WC under grazing in a farmlet system experiment.

Materials and methods

The experiment was established at Clonakilty Agricultural College, Clonakilty, Co. Cork, Ireland in 2012 and 2013 (75% of the area was reseeded in 2012 and 25% in 2013) and ran from February 2014 to November 2016. The experiment was a 2 × 2 factorial design; two PRG ploidies (tetraploid, diploid) and two WC treatments (grass-only, grass-clover) resulting in four grazing treatments (tetraploid only, diploid only, tetraploid + WC, diploid + WC). Eighty paddocks were used for the experiment, with 20 paddocks per grazing treatment. Within the tetraploid only and tetraploid + WC grazing treatments, four tetraploid (Astonenergy, Kintyre, Twymax and Dunluce) cultivars were sown ten times each, at a rate of 37 kg ha^{-1}, as monocultures with (n = 5) and without (n = 5) WC. Similarly, within the diploid only and diploid + WC grazing treatments four diploid (Tyrella, Aberchoice, Drumbo and Glenveagh) cultivars were sown ten times each, at a rate of 30 kg ha^{-1}, as monocultures with (n = 5) and without (n = 5) WC. In the WC paddocks a 50 : 50 mix of Chieftain and Crusader WC was sown at a rate of 5 kg ha^{-1}. Each grazing treatment was stocked at 2.75 cows ha^{-1} and rotationally grazed from early-February to mid-November each year. Target post-grazing sward height was 4 cm and nitrogen (N) fertiliser application was 250 kg ha^{-1} year^{-1} on all treatments. Each farmlet was walked weekly to monitor average farm cover and PastureBase Ireland (Hanrahan *et al.,* 2017) was used to calculate total, grazing and silage DM production. Post-grazing sward height was measured after grazing using a rising plate meter (Jenquip, Fielding, New Zealand). Sward WC content was measured before grazing on each paddock. Herbage samples were collected from each paddock before grazing for each treatment and freeze dried and milled through a 1mm sieve. Two replicates of each cultivar (with and without WC) were selected from four time points (February-March, mid-May to mid-June, mid-June to mid-July, September), giving 128 herbage samples each year that were subsequently analysed using wet chemistry techniques for DM, crude protein (CP), organic matter digestibility (OMD), acid detergent fibre (ADF), neutral detergent fibre (NDF) and ash. Data were analysed using PROC MIXED in SAS (SAS 9.4). Terms included in the model were year, cultivar, WC treatment, time point and their interactions.

Results and discussion

Perennial ryegrass cultivar had a significant effect ($P < 0.05$) on grazing, silage and total DM production (Figure 1). In terms of total DM production, there was 2.0 t DM ha^{-1} difference between the highest (Astonenergy – 17.3 t DM ha^{-1}) and lowest cultivars (Kintyre and Glenveagh – 15.3 t DM ha^{-1}).

Post-grazing sward height was affected ($P < 0.001$) by cultivar (Figure 1). Aston Energy had the lowest post-grazing sward height (3.95 cm) and Aberchoice had the highest (4.37 cm). Wims *et al.* (2013) also reported differences amongst PRG cultivars in terms of post-grazing sward height. Nutritive value varied significantly amongst cultivars ($P < 0.001$; Table 1); OMD ranged from 759 to 789 g kg^{-1}, CP from 206 to 225 g kg^{-1} and NDF from 409 to 450 g kg^{-1}. White clover inclusion increased total DM production ($P < 0.001$) but there was no interaction between PRG cultivar and WC inclusion ($P > 0.05$) in terms of total DM production. Sward WC content was affected ($P < 0.001$) by cultivar as annual sward WC content ranged from 190 (Drumbo) to 390 g kg^{-1} (Glenveagh).

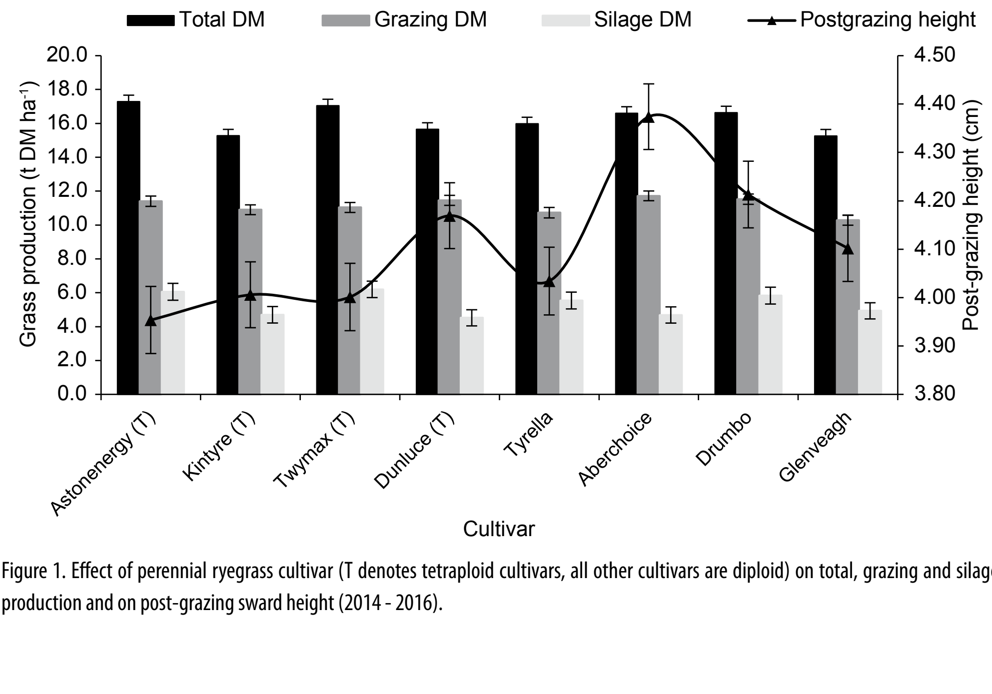

Figure 1. Effect of perennial ryegrass cultivar (T denotes tetraploid cultivars, all other cultivars are diploid) on total, grazing and silage DM production and on post-grazing sward height (2014 - 2016).

Table 1. Effect of cultivar (T denotes tetraploid cultivars, all other cultivars are diploid) on sward nutritive value (2014-2016).

	OMD[1] (g kg^{-1})	CP[2] (g kg^{-1})	NDF[3] (g kg^{-1})	ADF[4] (g kg^{-1})	Ash (g kg^{-1})
Astonenergy (T)	789	225	409	236	119
Kintyre (T)	768	223	423	249	116
Twymax (T)	767	216	429	252	112
Dunluce (T)	774	211	425	252	126
Tyrella	770	222	428	256	131
Aberchoice	762	206	439	266	125
Drumbo	760	208	450	267	125
Glenveagh	759	216	447	267	128
Standard Error	5.8	4.8	6.2	4.7	5.4
Year	< 0.0001	NS	< 0.0001	< 0.0001	< 0.0001
Cultivar	0.005	0.052	< 0.0001	< 0.0001	NS
Time point	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Cultivar*white clover treatment	< 0.0001	< 0.0001	< 0.0001	< 0.0001	NS

[1]OMD = organic matter digestibility, [2]CP = crude protein, [3]NDF = neutral detergent fibre, [4]ADF, acid detergent fibre.

Conclusion

Perennial ryegrass cultivar had a significant effect on herbage DM production, post-grazing sward height and sward nutritive value. White clover inclusion increased total DM production and sward nutritive value irrespective of cultivar. This highlights the potential to improve production in grazed swards by selecting superior cultivars and by including WC.

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The effect of grass ploidy and white clover inclusion on milk production of dairy cows

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Abstract

Grazed grass is considered the cheapest feed available for dairy cows in temperate regions and so to maximise profits, dairy farmers must utilise this high quality feed where possible. Recent research reported that including white clover in grass swards can have a positive effect on milk production. The aim of this study was to quantify the effect of tetraploid and diploid perennial ryegrass (*Lolium perenne* L.) swards sown with and without white clover (*Trifolium repens* L.) on the milk production of grazing dairy cows. Four grazing treatments were used for this study; tetraploid only grass swards, diploid only grass swards, tetraploid with white clover and diploid with white clover. Thirty cows were assigned to each treatment and swards were rotationally grazed at a stocking rate of 2.75 cows ha^{-1} and a nitrogen fertiliser application rate of 250 kg ha^{-1} annually. There was no significant effect of ploidy on milk production. Over the three year study, cows grazing the grass-white clover treatments had greater production in terms of milk yield (+ 728 kg cow^{-1}) and milk solids yield (+ 58 kg cow^{-1}) compared with cows grazing the grass-only treatments. This significant increase in milk production suggests the inclusion of white clover in grazing systems can be effectively used to increase milk production.

Keywords: perennial ryegrass ploidy, white clover, milk production

Introduction

Grazed grass is the cheapest feed available for dairy cows and dairy farmers must maximise the use of this high quality feed where possible (Finneran *et al.,* 2012). Previous research has shown that perennial ryegrass (*Lolium perenne* L.) ploidy can affect milk production as cows that grazed tetraploid swards produced significantly more milk and milk solids (kg fat + protein) than diploid swards (Wims *et al.,* 2013). Tetraploid swards often have a greater nutritional value, in particular, having greater digestibility when compared with diploid swards (O'Donovan *et al.,* 2005). The inclusion of white clover (*Trifolium repens* L.) in grazing systems has experienced renewed interest recently due to the well reported benefits in terms of milk production. An increase in milk production from cows grazing, grass-white clover swards has also been observed and can be attributed to an overall increase in herbage dry matter (DM) intake from grass-white clover swards (Ribeiro Filho *et al.,* 2005) and to the high nutritional value of white clover (Søegaard, 1993). The objective of this study was to determine the effect of perennial ryegrass ploidy and white clover inclusion on milk production of spring calving grazing dairy cows.

Materials and methods

The experiment was undertaken at Clonakilty Agricultural College, Clonakilty, Co. Cork, Ireland from February 2014 to November 2016. The experiment was a 2 × 2 factorial design; two perennial ryegrass ploidies (tetraploid, diploid) and two white clover treatments (grass-only, grass-white clover) resulting in four grazing treatments (tetraploid only, diploid only, tetraploid + white clover, diploid + white clover). In 2012, 75% of the area was reseeded and the remaining 25% was reseeded in 2013. Twenty blocks of four paddocks were created and balanced for location, topography and soil type. Each treatment was randomly assigned in each block and a separate farmlet of 20 paddocks was created for each treatment. Diploid swards were sown at a rate of 30 kg ha^{-1} and tetraploid swards were sown at a rate of 37 kg ha^{-1}. In the grass-white clover paddocks a 50:50 mix of Chieftain and Crusader white clover was sown at a rate of 5 kg ha^{-1}. There were 30 cows per treatment and each treatment was stocked at 2.75 cows ha^{-1}, with equal numbers of three breeds (n = 10) used in each treatment. The breeds used were Holstein-Friesian (HF), Jersey × HF and Norwegian Red × Jersey × HF. Within breed, cows were assigned to treatment based on calving date, parity and economic breeding index. Cows remained on their treatments for the entire grazing season in each year. Treatments were rotationally grazed from early-February to mid-November each year and target post-grazing sward height was 4 cm. Nitrogen fertiliser application was 250 kg ha^{-1} year^{-1}. Each farmlet was walked weekly to monitor average farm cover (Hanrahan *et al.,* 2017) and when surpluses arose they were removed in the form of baled silage. If a feed deficit occurred across all treatments then all treatments were supplemented with concentrate. On average, 322 kg concentrate was fed per cow per year. If a feed deficit occurred in an individual treatment then cows were supplemented with conserved forage produced from within that treatment. Pre-grazing herbage mass in each paddock was determined twice weekly by harvesting two strips using an Etesia mower (Etesia UK Ltd., Warwick, UK) in the area to be grazed next. Pre- and post- grazing heights were measured daily using a rising plate meter (Jenquip, Fielding, New Zealand). Sward white clover percentage was measured before grazing in each paddock in each rotation by cutting 15 random grab samples to 4 cm with a Gardena hand shears, separating the sample into perennial ryegrass and white clover fractions and drying at 60 °C for 48 hours. Milk yield was recorded daily and milk composition weekly by taking milk samples from a consecutive evening and morning milking. Data from 360 cows (120 in 2014, 2015 and 2016, respectively) were available for analysis. Milk data were analysed using Proc MIXED in SAS (SAS 9.4). Terms included in the model were year, ploidy, white clover treatment, parity, breed and their interactions.

Results and discussion

Perennial ryegrass ploidy had no significant effect on milk production or composition over the three years. White clover inclusion had a significant (P < 0.001) positive effect (Table 1) on milk production. Over the three years, grass-only swards produced, on average, 5,098 kg milk and 428 kg milk solids cow^{-1} year^{-1}, in comparison with the grass-white clover swards that produced 5,826 kg milk and 486 kg milk solids cow^{-1} year^{-1}.

There was no significant effect of ploidy or white clover inclusion on milk composition, with the exception of milk lactose percentage per cow which was greater on grass-white clover compared to grass-only. Typically, the difference in milk production between the grass-only and grass-white clover treatments occurred from May onwards as this was when sward white clover content started to increase as shown in Figure 1. Sward white clover content was on average, 24 and 26% in the tetraploid + white clover and diploid + white clover treatments, respectively. Ploidy had no significant effect on sward white clover content.

Table 1. Effect of perennial ryegrass ploidy (P) and white clover (WC) inclusion on milk production results (2014 - 2016).

	Tetraploid only	Diploid only	Tetraploid + WC	Diploid + WC	S.E.	P	WC	P × WC
Milk yield (kg cow^{-1})	5,086	5,110	5,842	5,809	57.6	0.937	<0.001	0.617
Milk solids yield (kg cow^{-1})	429	426	487	484	4.4	0.562	<0.001	0.972
Fat content (g kg^{-1})	45.3	46.2	45.9	46.3	0.46	0.406	0.676	0.794
Protein content (g kg^{-1})	37.2	37.0	36.9	36.7	0.18	0.461	0.331	0.990
Lactose content (g kg^{-1})	48.1	47.8	48.2	48.3	0.01	0.458	0.038	0.144
Milk yield (kg ha^{-1})	13,986	14,052	16,065	15,975	158.3	0.937	<0.001	0.617
Milk solids yield (kg ha^{-1})	1,178	1,172	1,338	1,331	12.2	0.562	<0.001	0.972

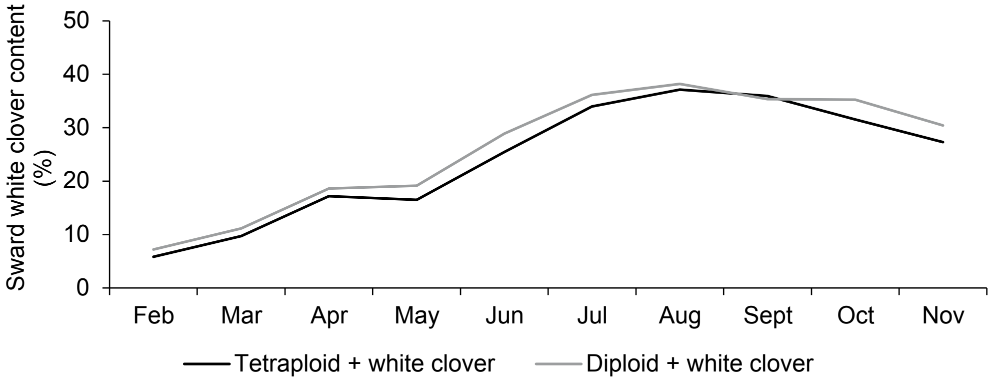

Figure 1. Average sward white clover content (%) by month of year for tetraploid + white clover and diploid + white clover treatments (2014 - 2016).

Conclusion

Perennial ryegrass ploidy had no effect on the milk production. The inclusion of white clover in both tetraploid and diploid swards had a significant positive effect on milk production.

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Grazing behaviour of dairy ewes as affected by spatial and time allocation of forage crops

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Abstract

Mixed pastures of *Lolium multiflorum* L. (L) and *Trifolium alexandrinum* L. (T) (treatment; Mix) were compared with adjacent pastures of the same species grazed in sequence (treatment; Grs) using a randomised block design with two replicates. Mid-lactation Sarda ewes were divided into four groups randomly allocated to treatment plots for 6 h daily (8:00 - 14:00), changing subplots after 3 h (T to L in Grs, LT to LT in Mix). Herbage intake rate (HIR, g DM min^{-1}) and feeding behaviour were measured in week (W) 1, 5 and 9. Sward height and herbage mass were not different between treatments. Clover proportion was higher in Grs than Mix ($P < 0.01$). Herbage intake rate was higher in Grs than Mix in h 1 ($P < 0.01$) when Grs ewes were grazing T but not in h 4, when they were grazing L. Herbage intake rate was higher in Grs than Mix ($P < 0.001$) in W 5 but not in W 1 or 9. Grazing time was unaffected by treatments whereas ruminating time was shorter in Grs than Mix ($P < 0.05$). To conclude, Grs enhanced clover proportion in the pasture and HIR when ewes were grazing the clover and its proportion in the pasture was high.

Keywords: sheep, nutrition, grazing management

Introduction

Forage legumes and grasses have complementary agronomic and nutritional features and therefore, are regarded as fundamental for the establishment of pastures for ruminants, such as dairy sheep (Molle *et al.*, 2007). However, little is known on the optimal allocation in space and time of these forages. Although the establishment of pastures as mixtures is the most widespread establishment method and has many advantages, some reports suggest that a side by side (conterminal monoculture) establishment can favour animal choice and increase intake and performance (Champion *et al.*, 2004). Another way to combine grass and legume forages in the diet of grazing ruminants is their use in sequence, according to a simple grazing circuit, in which legumes should be grazed first (Rutter, 2006). The aim of this study is to assess the effects of grazing either a binary grass-legume mixture (Mix) or the same forages as monocultures grazed in sequence (Grs) on foraging behaviour of dairy ewes.

Materials and methods

The experiment was run at Bonassai research station (north west Sardinia, Italy) from March to May 2016, lasting ten weeks in total. A randomised block design with two replicates was adopted. Pasture consisted of two one-hectare blocks, each divided in two experimental plots of 0.5 ha. One plot was sown with a mixture (Mix) of Italian ryegrass (*Lolium multiflorum* Lam., cv. Teanna; L) and berseem clover (*Trifolium alexandrinum* L., cv. Laura; T), the other was split into two subplots, sown respectively with monocultures of the same forage species (Grs). Seed rates were 35 kg ha^{-1} for the monocultures and 15 kg ha^{-1} (L) and 20 kg ha^{-1} (T) for the mixture. Fertilisation rates were 85 kg nitrogen (N) ha^{-1} and 40 kg phosphorous (P) ha^{-1} for L, 40 kg P ha^{-1} for T and 18 kg N ha^{-1} and 40 kg P ha^{-1} for Mix. After pasture establishment, each subplot was divided by electric fences into two 0.125 ha sub-subplots, which were grazed in sequence: from 8:00 to 11:00 h in sub-subplots 'a' (grazing session (GS) 1); from 11:00 to 14:00 h in sub-subplots 'b' (GS 2), with the pasture composition the same for Mix and different for Grs (a = berseem clover; b = ryegrass). Forty eight mature Sarda ewes in mid-lactation (mean ± s.d., 78 ± 6 days in milk) were divided on the basis of pre-experimental milk yield (2,090 ± 325 g $ewe^{-1}day^{-1}$), live weight (40.4 ± 4.7 kg) and body condition score (2.56 ± 0.22 units) into four groups of 12 ewes each, homogeneous for the above criteria. The ewes were machine-milked twice daily at 7:00 and 15:00 h. The ewes were supplemented daily with 500 g $head^{-1}$ of a commercial concentrate split into two equal meals fed at each milking, and 800 g $head^{-1}$ of a ryegrass-based hay fed at pasture turn-out. Each group rotationally grazed the allocated subplots, with 14 days of utilisation and 14 days of a regrowth period.

Sward height was measured using a weighted-plate grass-meter (50 random measurements per subplot on three occasions during each grazing cycle). Herbage mass was determined at the beginning of each grazing cycle by cutting three quadrats of 0.5 m^2 per subplot. Berseem clover proportion was then measured per subplot on a DM basis. Herbage samples were hand-plucked at 10:00 (sub-subplots a) or 12:30 (sub-subplots b), oven-dried at 65 °C for 72 h and then ground to determine the content of DM, crude protein (CP) and neutral detergent fibre (NDF; AOAC, 1990). Herbage intake rate (HIR, g DM min^{-1} grazing) was measured on five ewes per group using the double-weighing technique (Penning and Hooper, 1985) during week (W) 1, 5 and 9. Briefly, the ewes were weighed before and after the first hour of each grazing session (8:00 and 11:00) on a precise electronic scale. An additional ewe per group, which rotated among animals within group on each test day, was used to simultaneously estimate insensible weight losses. Grazing and ruminating times were measured by direct observation of the same five ewes per group every three minutes throughout the grazing sessions. Data were totalled by grazing session.

Pasture data were analysed by a factorial model with treatment (TRT), BLOCK, W, GS and the interactions TRT × W and TRT × GS. Animal data were analysed with a repeated model including TRT, BLOCK, W, GS, TRT × W, TRT × GS with animal as the error term. Differences between treatment means were assessed by Tukey *t* tests for multiple comparisons. Significance threshold was set at $P < 0.05$.

Results and discussion

Sward height and herbage mass were not different between Grs and Mix (Table 1). Clover proportion was higher in Grs than Mix ($P < 0.01$) and within Grs, tended to be higher in W 5 than W 1 and 9 (0.40, 0.28 and 0.26, respectively). Herbage DM content increased across the grazing period as expected (Table 1). Herbage CP content was higher in Grs than Mix, probably due to the higher clover content. Herbage CP content was also higher in the first (Grs grazing T) than the second (Grs grazing L) GS with an opposite trend for DM (not shown). Herbage NDF content was unaffected by the factors under examination, ranging between 350 and 400 g kg^{-1} DM (Table 1) which is regarded as optimal for dairy sheep during lactation (Cannas, 2004).

Herbage intake rate was higher in Grs than Mix in h 1 (8.9 vs 7.4 g DM min^{-1}, $P < 0.01$) when Grs ewes were grazing T but not in h 4, when they were grazing L (7.3 vs 7.1 g DM min^{-1}) in line with results of previous experiments (Molle *et al.*, 2017). Herbage intake rate was also higher in Grs than Mix in W 5 ($P < 0.001$) but not in W 1 or 9 (Table 1). Grazing time during the three hour grazing sessions was similar between treatments, whereas ruminating time was shorter in Grs than Mix ewes (12 vs 17 min, $P < 0.05$). This can be possibly related to a higher legume intake in GRS group.

Conclusion

To conclude, the establishment of L and T as conterminal monocultures grazed in sequence rather than as mixture enhanced the clover proportion in the pasture and CP herbage content in the diet. Moreover, Grs increased HIR but only when ewes were grazing the clover and clover proportion in the pasture biomass was high.

Table 1. Effects of the allocation of berseem clover and Italian ryegrass pastures as mixture (Mix) or grazing sequence (Grs, 8:00 - 11:00 h on clover and 11:00 - 14:00 h on ryegrass) on sward height (SH), herbage mass on offer (HM), proportion of clover in the HM, herbage composition (hand plucked samples) and herbage intake rate (HIR), grazing time (GT) and ruminating time (RT) of dairy ewes.

	SH cm	HM t DM ha^{-1}	Clover proportion	DM[1] g kg^{-1}	CP[1] g kg DM^{-1}	NDF[1] g kg DM^{-1}	HIR g DM min^{-1}	GT[2] min	RT[2] min
Mix W1	12.7^{c}	1.3^{c}	0.13^{bc}	135^{c}	224^{ab}	387	6.7^{b}	108^{b}	13^{ab}
Grs W1	13.9^{bc}	1.4^{c}	0.28^{ab}	131^{c}	253^{a}	350	6.3^{b}	112^{ab}	11^{ab}
Mix W5	13.6^{bc}	1.5^{c}	0.09^{c}	142^{c}	193^{c}	370	6.4^{b}	124^{ab}	15^{ab}
Grs W5	14.9^{bc}	1.7^{bc}	0.40^{a}	167^{ac}	199^{bc}	369	8.5^{a}	128^{a}	9^{b}
Mix W9	19.1^{ab}	2.4^{ab}	0.11^{c}	226^{a}	173^{c}	401	8.8^{a}	112^{ab}	22^{a}
Grs W9	20.9^{a}	2.7^{a}	0.26^{ab}	217^{ab}	186^{c}	388	9.4^{a}	107^{b}	15^{ab}
SEM[3]	0.6	0.1	0.02	10.0	7.0	6.0	0.2	2.0	1.0
Sig. Level[4]									
TRT	ns	ns	0.001	ns	0.01	ns	0.01	ns	0.05
W	0.001	0.001	ns	0.001	0.001	ns	0.001	0.001	0.05
GS	ns	ns	ns	0.01	0.001	ns	0.001	ns	ns
TRT × W	ns	ns	ns	ns	ns	ns	0.001	ns	ns
TRT × GS	ns	ns	ns	ns	ns	ns	0.01	ns	ns
BLOCK	0.05	ns	ns	ns	ns	ns	0.001	ns	ns

[1] DM = dry matter; CP = crude protein; NDF = neutral detergent fibre.

[2] GT = grazing time and RT = ruminating time during 3 h grazing sessions.

[3] SEM = Standard error of the mean.

[4] TRT = treatment; W = week; GS = grazing session; Means with different superscripts differ at $P < 0.05$; ns = $P > 0.05$.

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Resilience of *Festulolium* in terms of productivity and impact on soil characteristics under machinery compaction

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Abstract

Festulolium are ryegrass (*Lolium*) and fescue (*Festuca*) species' hybrids developed to combine their attributes, the stress tolerance of fescues, together with the forage quality characteristics of ryegrass. To investigate the potential of *Festulolium* to combat soil compaction, three *Festulolium* populations growing in field plots were compared against relevant ryegrass (cultivar AberBite) and fescue (cultivar Kora) controls. Triplicate grass plots were established in 2012 and maintained under a cutting regime. In spring 2016, plant tiller densities were determined prior to half of each plot being compacted using machinery. Following compaction, soil bulk density and dry matter (DM) yield were measured from the compacted and non-compacted half of each plot. In the autumn, destructive soil and plant characteristics were measured, including root biomass. Baseline data showed *Festulolium* cultivars had higher tiller number than Kora. Kora had a higher DM yield, but no difference in yield was observed between all *Festulolium* populations and AberBite. *Festulolium* population Lp × Fg (*Lolium perenne* L. × *Festuca glaucescens* Roth.) had a higher root biomass than AberBite and Kora in both compacted and non-compacted soil, respectively. With an equivalent DM yield to ryegrass, the *Festulolium* demonstrated additional benefits underground through their larger root systems.

Keywords: productivity, *Festulolium*, ryegrass, compaction

Introduction

The Agriculture and Horticulture Development Board (AHDB, 2015) reported that as much as 70% of grassland soils in England and Wales were showing signs of compaction as a consequence of livestock or farm machinery traffic. The resultant impact on soil is impaired water infiltration and increased anoxia, and on crops, late emergence, poor root penetration and decreased root growth directed towards water and nutrient uptake, which can lead to depressed crop yield. Furthermore, global climate change is challenging sustainable agricultural production and in particular, changing rainfall patterns with increased frequency, duration and intensity of extreme weather events such as floods. New targets for plant breeding to counteract soil compaction and climate change are vital in strategies for future United Kingdom (UK) grassland development. These have led to a demand for novel resilient and ecologically favourable grasses to replace high yielding but stress susceptible ryegrass (*Lolium*) varieties. *Festulolium* are hybrid combinations involving various ryegrass and fescue (*Festuca*) species (Humphreys *et al.*, 2014) developed to combine their main attributes, namely the stress tolerance found in fescues (derived in part from deep root systems), together with the high forage growth and quality characteristics in ryegrass (Macleod *et al.*, 2013). Their full potential, both as an agricultural alternative to ryegrass and for ecosystem service, is still to be discovered. Here, an experiment tested the hypothesis that *Festuloliums* have potential to be more resilient to soil compaction than current ryegrass varieties.

Materials and methods

This field experiment was conducted at IBERS, Aberystwyth (52° 26" N, 4° 0" W) on soil of the Rheidol series over a nine month period (February 2016 – October 2016) throughout one growing season using grass plots (5 × 1.2 m) established in autumn 2012 in a randomised block design with three replicated treatments. Between 2012 and 2015, plots were maintained under a five cut year^{-1} regime to simulate conservation management for silage. Three tetraploid *Festulolium* cultivars, Prior (*Lolium perenne* L. × *Festuca pratensis* Huds.*),* Lp × Fg *(Lolium perenne* L. × *Festuca glaucescens* Roth.*)* and Lp × Fm (*Lolium perenne* L. × *Festuca mairei* Hack.) were compared against two parental control grasses, perennial ryegrass (*Lolium perenne* L.) cultivar AberBite and fescue (*Festuca arundinacea* Schreb.) cultivar Kora. For baseline data, plant tiller density (TD) and soil bulk density (BD) were measured prior to compaction. Tiller density was measured as an aide to determining rooting potential (as the base of each grass tiller is a potential root source). Following this, a randomly selected half of each grass plot was compacted (17 March 2016) using a 2,040 kg weight ring roller at a rate of six passes per plot. The experiment structure compared the grasses and the effects of soil condition (SC) i.e. compacted or non-compacted. Following compaction, forage dry matter yield (DMY) was determined from four grass cuts harvested using a Haldrup 1500 plot harvester at a cutting height of 5 cm. After the fourth harvest cut (04 October 2016), soil and plant measurements taken for baseline data were reassessed using the compacted and non-compacted sub-plots. Soil cores were used to determine and calculate root biomass. Single factor analysis of variance (ANOVA) was used to analyse TD data while two factor ANOVA and GenStat® release 18 was used to analyse post-compaction data.

Results and discussion

Following compaction, soil BD confirmed that the compaction treatment imposed did compact the soil, with higher BD on compacted (1.40 ± 0.01) compared to non-compacted (1.34 ± 0.01) sub-plots ($P < 0.05$). In this study, TD of the plots involving all three *Festulolium* cultivars were significantly higher than Kora (Fescue control) prior to compaction (Table 1). After compaction, TD numbers were not significantly varied amongst the grasses (data not shown). Compared to non-compacted, TD declined significantly in the compacted sub-plots by 12.7%, 9.74%, 9.44% for AberBite, Prior and Lp × Fm, respectively. For Lp × Fg the decline in TD was only 0.38% while it was 3.70% for Kora. Forage annual DMY was significantly higher in Kora for both SC. The DMY of the *Festulolium* cultivars did not differ from AberBite (Table 1). For root biomass, there were significant interactions for grass × SC. *Festulolium* cultivar Lp × Fg had the highest root DM biomass within the top 30 cm of the soil layer in both compacted and non-compacted soil whilst AberBite had the lowest root biomass in the compacted soils ($P < 0.05$). Kora and Prior had the lowest root biomass in the non-compacted sub-plots. AberBite and Lp × Fm had a significant reduction in root biomass as a result of compaction (23.5 and 19.3%, respectively). In contrast, both Prior and Kora increased their root size in compacted sub-plots and behaved similarly to the stress (Table 1). Overall, before compaction, all three *Festulolium* cultivars had higher a number of tillers compared to Kora. Under compaction, grass TD was reduced with AberBite most affected. Forage production by all three *Festulolium* was similar to AberBite statistically in terms of annual DMY when under compaction, although Kora had a higher DMY. However, tall fescue, Kora is slower growing and its yield advantage was not evident in the early years of the field trial (Humphreys *et al.*, 2014). As a result of compaction, AberBite had lost a considerable amount of root biomass while Lp × Fg retained significantly higher root biomass. Unique amongst the grasses, *Festulolium* cultivar Prior increased its root biomass in the top 30 cm of compacted soils. Macleod *et al.* (2013) demonstrated that the *Festulolium* cultivar Prior reduced runoff by 43% compared to its fescue parent. This was explained, at least in part, as being due to its large root system. In the current work, root biomass under Lp × Fg supports the results of Macleod *et al. (*2013), with the lowest root biomass in compacted soils found in AberBite and in Kora in non-compacted soils.

Conclusion

Productivity of *Festulolium* and AberBite in terms of forage yield was not significantly different, but certain *Festulolium* cultivars were superior in their root production under soil compacted by machinery.

Table 1. Mean tiller density (TD; tillers 0.1 m^{-2}) before compaction, DMY (dry matter yield) and RB (root biomass) after compaction (C = compacted vs NC = non - compacted) for three *Festulolium* cultivars (*Lolium perenne* L. (Lp) × *Festuca mairei* Hack.), Lp × *Festuca glaucescens* Roth. and Prior), ryegrass (AberBite) and fescue (Kora) in 2016.

Grass		Before compaction (baseline) spring	After compaction (compacted vs non-compacted) autumn			
		TD	DMY (C) kg DM ha^{-1}	DMY (NC) kg DM ha^{-1}	RB (C) kg m^{-3}	RB (NC) kg m^{-3}
AberBite		202^{ab}	$14{,}745^{a}$	$14{,}917^{a}$	2.5^{a}	3.3^{bcd}
Kora		185^{a}	$17{,}738^{b}$	$17{,}445^{b}$	3.1^{abcd}	2.7^{ab}
Lp × Fm		226^{b}	$13{,}825^{a}$	$14{,}042^{a}$	2.8^{abc}	3.4^{bd}
Lp × Fg		226^{b}	$13{,}302^{a}$	$14{,}342^{a}$	3.5^{bcd}	3.6^{d}
Prior		232^{b}	$13{,}566^{a}$	$13{,}532^{a}$	3.0^{abcd}	2.7^{ab}
SEM	Grass (G)	0.27^{*}	0.01^{**}		0.23	
	Soil condition (SC)		0.004^{**}		0.08	
	G × SC		0.01^{**}		0.27	
P-values	Grass (G)	0.011	< 0.001		0.239	
	Soil condition (SC)		0.217		0.159	
	G × SC		0.262		0.042	

Treatment values within columns with differing lower case superscript differ significantly. * Standard errors of means (SEM) derived from square root transformed data; ** SEM derived from log transformed data.

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Validation of model based herbage quality estimations on minerotrophic fen grasslands

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Abstract

Permanent grasslands in northeast Germany are characterised by extensive to semi-intensive use of minerotrophic fen soils. This kind of management results in a mixture of heterogeneous swards with diverse indigenous plants differing in forage quality. Good knowledge of the forage value of these stands is crucial for optimal forage utilisation. An additive herbage evaluation model was validated by independent herbage samples that were botanically described and analysed for a range of forage value parameters. Model-derived estimates of crude protein (XP), crude fibre (XF) and metabolisable energy (ME) content from fen pasture growths were compared with corresponding analytical data for this purpose. Results of the validations show the need for adjustment in the case of XP estimations and the limits of the model's capability if applied to fibre-related parameters of heterogenous fen pasture growths. Our findings suggest that while the forage value dynamics over time can be widely captured by the implementation of a site-specific additive correction term into the model under regular fen grassland use conditions (mowing or rotational grazing), further model development involving additional physiological parameters such as compressed sward height seems to be necessary to achieve satisfactory results under extensive permanent grazing regimes.

Keywords: forage quality, fen grassland, estimation, model validation

Introduction

Permanent grasslands in northeast Germany are characterised by extensive to semi-intensive use of minerotrophic fen soils due to the low dairy density in this region (Müller and Heilmann, 2011). Suckler cow husbandry in organic farmed systems dominates grassland use. This kind of management results in a mixture of heterogeneous swards with diverse autochthonous plants differing strongly in forage quality (Bockholt and Buske, 1997). Good knowledge of the forage value of these stands is crucial for planning optimal forage utilisation (Pickert and Müller, 2016). While forages for dairy winter feed rations are regularly analysed, data on the quality of grazing swards on offer are usually unavailable and standard values are often unreliable for specific site conditions. Using botanical sward composition to make an approximate estimate of the forage stand value is an old idea already applied in Klapp's value score scheme (Klapp *et al.*, 1953). However, this score scheme is not really evidence-based, not very transparent in the way the final assessments for single plants were made, and thus cannot seriously replace forage analysis as demanded by contemporary husbandry. Using model estimations of forage values based on measured quality parameters of sward forming plants (Dittmann and Bockholt, 2005) instead of score schemes seems a promising way to close the gap between raw tabled values and expansive exactly analysed parameters. The model described by Dittmann and Bockholt (2005) was adjusted to the site of plant collection (Recknitz Valley) under regular cutting treatments, but not evaluated at any other site, management or vegetation backgrounds. Therefore, the aim of this study is to evaluate the suitability of this model for a broader application on diverse fen grassland communities under an extensive grazing regime.

Materials and methods

The study was conducted at a semi-natural minerotrophic fen grassland site (Peene Valley, West Pomerania) with native plant communities harbouring typical species of peaty soils that were covered by the model of Dittmann and Bockholt (2005). Seventy mixed plant samples were collected along a transect after estimation of plant composition at each of the fourfold replicated sample points (50 × 50 cm) from the beginning of May until the end of June. Herbage samples were oven dried at 45 °C, milled through a1 mm screen and analysed for a range of quality parameters including crude protein (XP, Kjeldahl) and crude fibre (XF, Weender) as described by Naumann and Basler (1993). The metabolisable energy (ME) content of herbage samples was calculated as described by Weißbach *et al.* (1999). Crude protein, XF and ME contents served as reference values for the validation. The model predictions of these parameters were calculated as weighted means of the time-dependent modelled XP, XF and ME-values for each single species *i* found in a herbage collection *j*. Field-estimated biomass percentages of each sample were used as weighting factors as follows:

$$\overline{fv_j} = \frac{\sum_i^n pc_i * fvi}{100} \tag{1}$$

where fv_j is the weighted forage value mean of a single herbage sample, pc_i is the estimated percentage of a species *i* in this sample, fv_i the model-derived forage value parameter of a single species, fv_i = f(time).

To validate the modelled forage value estimations, correlation and regression analyses with the references, values derived from chemical analyses were applied. All biometrical analyses and figures were developed using scripts written in the statistical computing environment of R (R Development Core Team, 2017).

Results and discussion

Results of the validation revealed a slight slope and a noticeable bias trend when CP values were calculated using the model (Figure 1). In contrast, the XF content as a fibre-related trait showed a more scattered pattern indicating limited accuracy of fit when using the described estimating procedure. Since fibre and cell wall related traits are quite relevant for ME-calculation (Weißbach *et al.*, 1999), it is not surprising that ME values also could not meet the accuracy requirements. However, bias adjustments have a certain potential to fit the values (Figure 2). It seems to be worthwhile to select 10% of the samples of a new fen study site randomly for a fast forage quality check using near infrared reflectance spectroscopy (NIRS) to attain a basis for such suggested bias adjustments.

Although the standard errors of prediction were larger than 3.5%, the information seems to be more valuable for decisions regarding the best use of the forage growth in animal husbandry than suggestions based on pure and static forage indicator values.

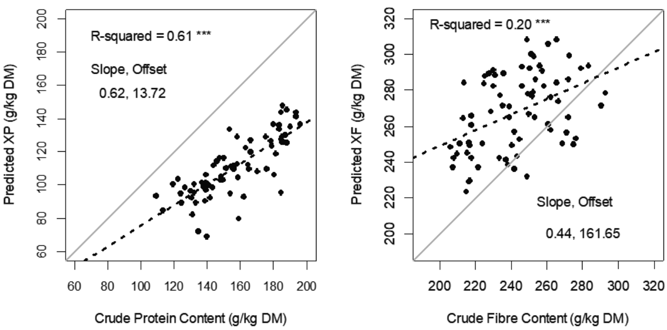

Figure 1. Validation plots of crude protein (left) and crude fibre (right) contents. The reference values are shown on the x-axis, the correspondent model-derived values at the y-axis. The bisector is drawn as a grey line and indicates paired values with ideal estimation accuracy. The dashed line gives the linear trend of the estimation function.

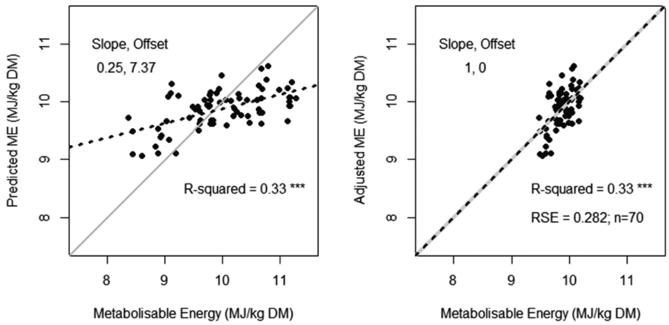

Figure 2. Validation plot of metabolisable energy before (left) and after (right) bias and slope adjustment. The reference values are shown on the x-axis, the correspondent model-derived values at the y-axis. The bisector is drawn as a grey line and indicates paired values with ideal estimation accuracy. The dashed line gives the linear trend of the estimation function.

Conclusion

Findings suggest that forage value dynamics over time can be captured by the implementation of a site-specific additive correction term into the model under regular fen grassland use conditions like mowing or rotational grazing. Further model development involving additional physiological parameters such as compressed sward height and/or stage of regrowth is necessary to gain satisfactory results under extensive permanent grazing regimes.

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Effects of cutting, burning and mulching on soil and plants in the Guinea Savanna-grassland

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Abstract

Recently the pastoralists in Nigeria's Guinea savanna have been experiencing tough challenges of insufficient pastures. The indigenous traditional method of cut-litter removal was associated with the low plant diversity in the region. Thus, an experiment with unconventionally novel management was established to evaluate the effects of cutting, burning and mulching on plant species richness and biomass production. The treatments applied included: cut-burn, cut-litter removal, cut-litter abandonment, twice mulching per year, once mulching per year and unmanaged control. It was hypothesised that cut-litter abandonment and mulching treatments would increase mineralisation, which would consequently increase biomass production in contrast to the traditional culture of cut-litter removal. The results revealed that biomass production was higher in cut-litter abandonment than conventional cut-litter removal. Species richness was significantly correlated with N, K, and P stocks.

Keywords: grassland management, nutrient stock, Guinea savanna

Introduction

Grasslands cover about two-thirds of African land area, with Guinea savanna (GS) having the largest area (Nwaogu *et al.*, 2016). The GS has typically been characterised by poorly managed burning, cutting and mulching. Proper management of the grassland will produce a high yield of biomass in the area. For example, cut-litter abandonment and crop-residue mulching are recommended methods for grassland development as they increase soil mineral nutrient availability by promoting mineralisation (Prosdocimi *et al.*, 2016). Burning, on the other hand, increases fodder production and quality compared to cut-litter abandonment and crop-residue mulching. In Nigeria, the GS belt was rich in species diversity and arable agriculture (Manyong *et al.*, 2001), but lately, unsustainable management (such as cut-litter removal) has contributed to a high rate of soil degradation and low species diversity. It is, therefore, hypothesised that cut-litter abandonment and mulching treatments will increase N mineralisation, which consequently increases biomass production relative to the traditional culture of cut-litter removal and burning. Within this context, the following research questions were addressed: (1) what effects have cutting and mulching on the species diversity and biomass production? (2) what are the relationships between N, P, K stocks and species richness?

Materials and methods

Between 2010 and 2015, an experiment with a block design with six treatments and four replicates was undertaken. The treatments were cut-burn (CB), cut-litter removal (C-L), cut-litter abandonment (C + L), twice mulching per year (2 M), once mulching per year (1 M), and unmanaged control (U). Four soil sub-samples from individual treatment plots were randomly collected from 0 - 15 cm soil depth. Debris, plants residues and pebbles were removed from the soil samples and prepared for laboratory analyses. The collected soil and plant samples were analysed for nitrogen (Ntot), phosphorus (P) and potassium (K) using the micro-Kjeldahl method (Bremner and Mulvaney, 1982) and Mehlich III solution (Mehlich, 1984), respectively. To generate the available nutrient stocks, soil bulk density was determined using the clod method (Blake and Hartge, 1986). Subsequently, the soil nutrient stocks of the monitored elements were determined (Bond, 2010). The plant biomass dry matter (DM) production in all the treatments was calculated after harvesting in each year. To evaluate the effects of treatments on the plant biomass, a one-way ANOVA was used. Significance differences (P < 0.05) between treatments in accordance with the Tukey's post hoc test is shown by lowercase letters (a > b > c > d > e > f), and ns = not significant. The relationships between the stocks of N, P, K and biomass production were analysed using linear regression analysis.

Results and discussion

The mean biomass production (t DM ha^{-1}) recorded during the study was in the order of C+L > 2M > 1M > CB > U > C-L (Figure 1). The high rate of N mineralisation in the cut with litter and the mulching regimes increased the soil nutrients, resulting in increased biomass production. This was a good indication that C + L was more productive than C - L. Significant relationships were recorded between species richness and the stocks of N (R^2 = 0.82; P < 0.001), K (R^2 = 0.78; P < 0.001), P (R^2 = 0.62; P = 0.023) and biomass DM production (R^2 = 0.51; P = 0.048) (Table 1). This might be attributed to improved soil fertility due to increased N mineralisation. More legumes were found on the burnt plots when compared with the cut and mulching plots where grasses dominated. This was probably because the legumes have higher fire-resistant seed coats than the grasses (Fidelis *et al.*, 2016). Most legumes in this study have the potential to fully recover after fire. Cutting and burning decreased the richness and biomass content of trees and shrubs, thus there were higher numbers of those in the unmanaged plots. This could be caused by the decrease in the organic matter, carbon and starchy contents of the stems and roots due to cutting (Latt *et al.*, 2000), as these chemical substances are essential for the growth of these species.

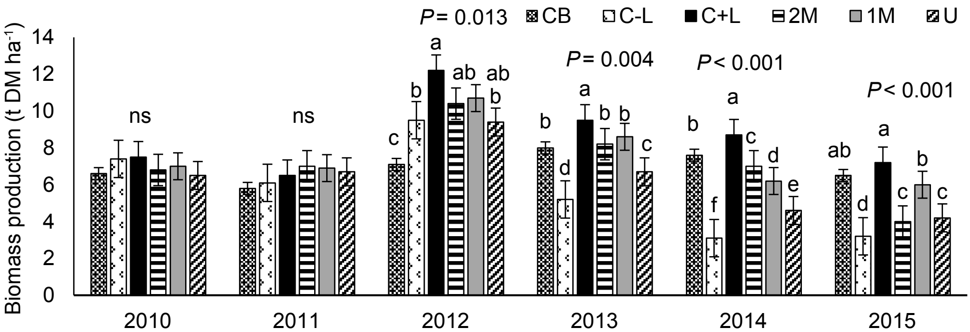

Figure 1. Dry matter biomass production from the different treatments from 2010 - 2015. Error bars represent standard error of the mean (SEM). Treatment abbreviations are CB = cut-burn, C - L= cut-litter removal, C + L = cut-litter abandonment, 2 M= twice mulching per year, 1 M=once mulching per year, U=unmanaged control.

Table 1. Relationships between species richness and N stock, K stock, P stock and DM biomass production.

Parameters	Regression equations	R^2	P-value
N stock and species richness	Y = 0.0571x + 15.532	0.82	< 0.001
K stock and species richness	Y = 0.1971x + 7.4063	0.78	< 0.001
P stock and species richness	Y = 0.0866x + 13.163	0.62	0.023
DM biomass production and species richness	Y = 2.6087x + 9.0629	0.51	0.048

Conclusion

Plant biomass DM production was significantly higher in the cut with litter and mulching regimes relative to the unmanaged and burnt treatments, while fire increased the species richness. Therefore, to increase the species richness in the study area, fire is a good option. If regulated, it can increase biomass production in the longer-term.

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Nutrients in the soil and herbage of tall sward-height patches under intensive and extensive grazing

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Abstract

Faeces are one of the key drivers affecting the sward structure and nutrient cycling on pastures. The effect of extensive and intensive grazing of heifers on nutrient concentration in the herbage and the soil under tall sward height patches were studied in an upland area in the Czech Republic. Three types of tall height sward patches (> 10 cm) were identified: (1) tall sward height patches with faeces under intensive grazing; (2) tall sward height patches with faeces under extensive management; (3) tall sward height patches with no faeces under extensive management, and were compared with regularly grazed swards in intensive and extensive grazing management. The analyses indicated no significant effect of different types of patches on soil available nutrients. The different types of patches had a significant effect on herbage concentration of P, K and Mg but no effect was detected for Ca and N. The highest nutrient concentration in the herbage, the lowest dry matter standing biomass, sward height and proportion of dead plant biomass were detected in tall sward height patches with faeces under intensive grazing. It is likely that nutrients from faeces were directly used by the existing plants in the tall sward patches and, therefore, soil enrichment was very low.

Keywords: heifers grazing, faeces, pasture vegetation, stocking intensity

Introduction

Grazing creates heterogeneous sward structure with heterogeneous height, which in turn, affects the floristic composition and heterogeneity of species in grasslands (Sasaki *et al*., 2005). Selective defoliation, which is mainly due to dietary choice of grazing animals, is one of the main mechanisms that cause heterogeneous sward structure. Selection of which patch to graze or neglect also depends on the visual cue of the herbivore indicating the forage quality or quantity and the size of the patch itself (Wallis DeVries *et al*., 1999). Cattle avoid the tall stem herbages where the leaf materials are difficult to graze (DeVries and Daleboudt, 1994) and areas that are contaminated by faeces because of the smell (Dohi *et al*., 1999). The objective of this study was to determine the effects of different grazing intensities of heifers on the nutrient concentration in the soil under tall sward height patches and in the herbage in *Agrostis capilaris* grassland.

Materials and methods

The study site was located in the Jizerské hory mountains in the northern part of the Czech Republic, 10 km north of the city of Liberec (50°50.34' N, 15°05.36' E) in Oldřichov v Hájích village. The altitude is 420 m above sea level, the mean annual temperature is 7.2 °C and average annual precipitation is 803 mm. The experiment site was established in 1998 in two completely randomised blocks (Pavlů *et al*., 2006). Paddocks were continuously stocked by young heifers (Czech Fleckvieh) from early May until late October in 2013. The selected study patches under particular grazing intensity are described in Table 1. Herbage biomass and soil samples were taken in September 2013. The biomass was dried at 80 °C, DMSB (dry matter standing biomass) and DM (dry matter) concentration of N, P, K, Ca and Mg were analysed.

Table 1. Description of the sward height patches and grazing intensity.

Treatment abbreviation	Grazing management	Patch type	Faeces presence	Stocking rate
IG_R	Intensive grazing with target sward surface height < 5 cm	regularly grazed sward	–	1000 kg live weight per 1 ha
IG_TF	Intensive grazing with target sward surface height < 5 cm	non-grazed or extensively grazed tall sward patches > 10 cm	+	1000 kg live weight per 1 ha
EG_R	Extensive grazing with target sward surface height > 10 cm	regularly grazed sward	–	500 kg live weight per 1 ha
EG_TF	Extensive grazing with target sward surface height > 10 cm	non-grazed or extensively grazed tall sward patches > 10 cm	+	500 kg live weight per 1 ha
EG_T0	Extensive grazing with target sward surface height > 10 cm	non-grazed or extensively grazed tall sward patches > 10 cm	–	500 kg live weight per 1 ha

Under each patch, soil samples were taken from the upper 10 cm of the soil profile. The soil samples were air dried and ground to pass through a 2 mm sieve. Basic analysis for determining plant available P, K, Ca, Mg, organic C content (C_{org}), pH/$CaCl_2$ were performed using Mehlich III extraction (Mehlich, 1984). Total nitrogen (N_t) was determined by Kjeldahl method. All chemical analyses for soil and herbage were performed in an accredited laboratory at the Crop Research Institute in Chomutov. A one-way ANOVA and RDA analysis was used to analyse soil and herbage data.

Results and discussion

The RDA analysis showed a significant ($P < 0.001$) difference for the first ordination axis and all axes in the soil and the herbage nutrient concentration. The percentage of explained variability by the first and second ordination axes was 60.0 and 69.4, respectively (Figure1). The highest nutrient concentration was revealed under both patches under intensive grazing (IG_R and IG_TF). The type of patches did

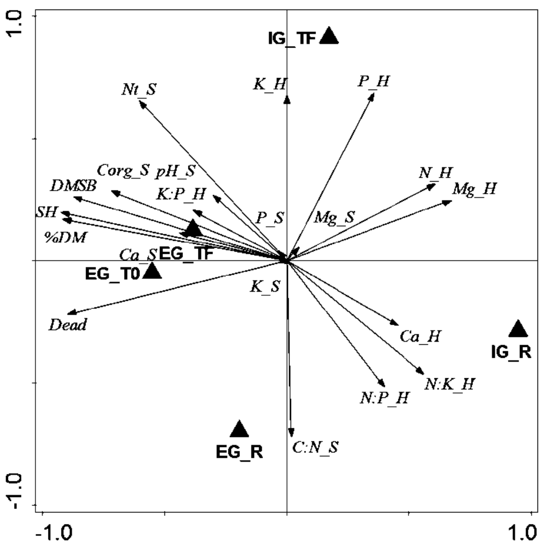

Figure 1. Ordination diagram showing the result of RDA analysis of mineral concentrations in the soil (X_S) and in the herbage (X_H) under different patches. Abbreviations are explained in Materials and methods.

not show any significant effect (one way ANOVA) on the concentration of plant available nutrients P, K and Mg in the soil. The presence of faeces increased ($P < 0.001$) N, P and K concentrations in intensively grazed pasture (IG_TF). No effect of the faeces presence on N, P and K concentrations was found in extensively grazed pasture. A higher DM content and DMSB under EG_TF and EG_T0 compared to IG_R and IG_TF was connected to the herbage maturity and dead plant biomass proportion of the sward. Generally, DM content in the herbage and DMSB increases with aging in central European upland grasslands (Pavlů, 2015) and the proportion of dead plant biomass increases with extensive management (Pavlů *et al*., 2012). A higher concentration of Mg and Ca in the herbage in regularly grazed sward was connected with a higher proportion of white clover and dandelion in the sward (Ludvíková *et al*., 2015) as these prostrate herbs have higher Mg and Ca concentrations in the herbage (Whitehead, 2000).

Conclusion

There was no effect of heifer faeces under intensive and extensive grazing management on P, K and Mg concentration in the soil under the tall sward height patches. It is likely that nutrients from heifer faeces were directly used by the existing plants and, therefore, soil enrichment was very low. The presence of faeces increased N, P and K concentration in the herbage in tall sward height patches in intensively grazed pasture only, whereas no effect of faeces due to 'dilution effect' was revealed in extensively grazed pasture.

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Performance of seed mixtures containing tall fescue (*Festuca arundinacea* Schreb.) for permanent meadows in mountain areas

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Abstract

Suitable strategies are required to face the recurrent drought periods in the southern region of the Alps. Because of its tolerance against drought, tall fescue (*Festuca arundinacea* Schreb.) has been targeted as a desirable component of seed mixtures for the establishment of permanent meadows under mountain environment. In a four year field experiment at two drought-endangered sites at altitudes of 835 and 1,200 m a.s.l., four seed mixtures (two seed mixtures already in use in practice and two seed mixtures containing respectively 40 and 60% seed weight of tall fescue) combined with three cutting frequencies (2, 3 and 4 cuts y^{-1}) coupled with increasing fertilisation rates (1, 1.4 and 2 livestock units ha^{-1}), were investigated. Dry matter yield and forage quality, including *in vitro* digestibility, were assessed for the trial's duration. Only small differences between the seed mixtures were ascertained across the observation period. For the seed mixtures containing tall fescue, a slight reduction of the *in vitro* digestibility at higher management intensity for one of the two seed mixtures and different content in magnesium and manganese were detected. It is concluded that the seed mixtures including tall fescue perform similarly to those already in use.

Keywords: *Festuca arundinacea* Schreb., seed mixtures, permanent meadows, forage quality

Introduction

Because of its tolerance to drought conditions, tall fescue (*Festuca arundinacea* Schreb.) has been recently targeted as a desirable component of seed mixtures for the establishment of permanent meadows in south-exposed mountain areas, characterised by shallow soils with light texture and endangered by recurring drought spells. Reasonable DM yield and forage quality were achieved in a first attempt to develop a seed mixture for intensive use in a mountain environment (Peratoner *et al.*, 2010). In a four year trial at two mountain sites, high management intensity was found to be favourable to the establishment and persistence of tall fescue over time (Peratoner *et al.*, 2017). The present paper focuses on results from the same field trial concerning yield and forage quality.

Materials and methods

The field trial was conducted at two experimental sites: San Genesio/Jenesien (835 m a.s.l., 46°31'25''N 11°20'22''E) and Falzes/Pfalzen (1,205 m a.s.l., 46°49'18''N 11°53'42''E) with the aim of optimising the composition of a seed mixture with tall fescue to be used for non-irrigated permanent mountain meadows at drought-endangered locations. Two factors were studied in this experiment: seed mixture (SM) and management intensity (MI). Two seed mixtures containing a relatively high proportion of a soft-leafed and a rough-leafed cultivar (Barolex and Kora, respectively) of tall fescue (Fa40 and Fa60, containing the same species, but 40 and 60% seed weight of tall fescue, respectively) were compared with a simple seed mixture for intensive use at low altitude and good water availability with a high proportion of *Lolium perenne* L. (DWi-t), and with a more complex mixture for less intensively managed sites at low altitude with limited water availability (DW-t), with *Arrhenatherum elatius* L. as a lead species (Table 1). Three MI levels were applied: low: 2 cuts y^{-1} coupled to a target fertilisation level equal to 1 livestock unit (LU) ha^{-1}; medium: 3 cuts y^{-1} coupled to a fertilisation level equal to 1.4 LU ha^{-1}; high: 4 cuts y^{-1} coupled to a fertilisation level equal to 2 LU ha^{-1}. The plots were fertilised with the farm's own manure. Because of fluctuations of the nutrient content of the manure, the actual fertilisation levels ranged between 1.1 and 2.2 LU ha^{-1} in San Genesio/Jenesien and between 0.8 and 1.9 LU ha^{-1}in Falzes/Pfalzen. The experimental design was a Latin rectangle with three replications and a plot size of 4 × 4 m. Forage yield and quality were measured for the duration of the trial. Crude protein (CP) was determined according to the Dumas method; crude fibre (CF), newtral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) were analysed by means of an Ankom 200 Fiber Analyser (Ankom Technology, Fairport, USA). *In vitro* digestibility (DOMD) was measured according to Tilley and Terry (1963). Ash (CA), minerals and trace elements were determined according to Naumann *et al.* (1997). Statistical analysis was performed on summary variables across years (mean values for the DM yield, weighted means with respect to the yield of the single cuts for the quality parameters) by means of mixed models taking into account SM, MI and their interaction as fixed factors. The design factors and the experimental site were considered to be random. Post hoc comparisons were performed by LSD test. The Satterthwaite correction for degrees of freedom and the NOBOUND option were used in SAS 9.2 for UNIX. Data transformation (cubic root for CA and iron (Fe), logarithm for copper (Cu)) was performed to fulfil the prerequisites for ANOVA. A probability of $P < 0.05$ was regarded as significant.

Results and discussion

Over the four year period, the seed mixture affected only the content of Mg and Mn. The differences between seed mixtures were small (Table 2). Fa 60 exhibited the highest content of magnesium (Mg), whilst Fa40 had an intermediate one. Fa40, Fa60 and DW-t contained about 7 mg kg^{-1} of manganese (Mn) less than DWi-t. For the remaining parameters, including also forage DM yield, no significant effect of the seed mixture was detected.

As expected, because of the different phenological stage at the harvest time of the first cut, CP, NDF and ADF as well as the content potassium (K) and zinc (Zn) were affected by MI. Increasing MI resulted in an increase of CP, K and Zn, whilst NDF and ADF decreased (Table 3).

For the *in vitro* digestibility, an interaction of SM and MI was detected ($P = 0.0397$). Lower MI led to lower digestibility due to the more advanced phenological stage at the first harvest, but this effect was more pronounced for DWi-t than for the other SM. At this MI level, tall fescue was the dominant species

Table 1. Composition of the investigated seed mixtures (DW-t, Fa40, Fa60 and DWi-t) in percentage seed weight. Ae = *Arrhenatherum elatius* L., Dg = *Dactylis glomerata* L., Fa = *Festuca arundinacea* Schreb., Fp = *Festuca pratensis* Huds., Fr = *Festuca rubra* L., Lp = *Lolium perenne* L., Php = *Phleum pratense* L., Pop = *Poa pratensis* L, Lc = *Lotus corniculatus* L., Th = *Trifolium hybridum* L., Tr = *Trifolium repens* L. [rl] rough-leafed, [sl] soft-leafed.

Seed mixture	Ae	Dg	Fa [rl]	Fa [sl]	Fp	Fr	Lp	Php	Pop	Lc	Th	Tr
DW-t	12	10			15	15	10	5	20	4	3	6
Fa40	13	14	20	20		5	4	3	15			6
Fa60	9	8	30	30		4	3	2	10			4
DWi-t		30					30		30			10

Table 2. Effect of the seed mixture (DW-t, Fa40, Fa60 and DWi-t) on the content of magnesium (Mg) and manganese (Mn). Means without letters in common significantly differ from each other ($P < 0.05$).

Element	DW-t	Fa40	Fa60	DWi-t
Mg (g kg^{-1} DM)	2.50^{c}	2.63^{b}	2.72^{a}	2.63^{b}
Mn (mg kg^{-1} DM)	103.1^{b}	105.1^{b}	104.7^{b}	111.5^{a}

Table 3. Effect of the management intensity (low = 1 LU ha^{-1}; medium = 1.4 LU ha^{-1} and high 2 LU ha^{-1}) on crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), potassium (K) and zinc (Zn). Means without letters in common significantly differ from each other ($P < 0.05$).

Management intensity	**CP (g kg^{-1} DM)**	**NDF (g kg^{-1} DM)**	**ADF (g kg^{-1} DM)**	**K (g kg^{-1} DM)**	**Zn (mg kg^{-1} DM)**
Low	105.3^{c}	572.1^{a}	366.3^{a}	25.0^{c}	33.5^{b}
Medium	123.2^{b}	539.7^{b}	341.9^{b}	29.3^{b}	37.6^{ab}
High	139.7^{a}	505.2^{c}	323.9^{c}	32.1^{a}	41.7^{a}

Table 4. Effect of the seed mixture (DW-t, Fa40, Fa60 and DWi-t) on i*n vitro* digestibility (g kg^{-1} DM). Means without letters in common significantly differ from each other. Means without upper case letters in common within each seed mixture (SM) and means without lower case letters in common within each management intensity (MI) level significantly differ from each other ($P < 0.05$).

Management intensity	**SM**			
	DW-t	**Fa40**	**Fa60**	**DWi-t**
Low	556.0^{Ba}	558.8^{Ba}	548.3^{Ba}	530.1^{Bb}
Medium	605.2^{Aa}	600.9^{Aa}	604.4^{Aa}	596.7^{Aa}
High	619.9^{Aa}	600.2^{Ab}	612.6^{Aab}	612.4^{Aab}

in Fa40 and Fa60. At higher MI, which is the level at which tall fescue in this experiment developed higher yield proportions over time (Peratoner *et al.*, 2017), Fa40 had the lowest DOMD, whilst Fa60 exhibited intermediate values.

Conclusion

These findings suggest that SM containing tall fescue are similarly suited to those already used in practice at low altitudes and low MI (DW-t). The use of Fa40 and Fa60 seems to be advisable at high MI, if a high yield proportion of tall fescue is desired. Further data analysis is required to elucidate the response of Fa40 and Fa60 to single dry spells during regrowth and, therefore, to get a better insight about the advantages or disadvantages of these seed mixtures.

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Selective grazing and nutrient transfer through cattle interactively affects pasture vegetation

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Abstract

Livestock grazing, as a sustainable management strategy, plays a key role in maintaining plant diversity. Grazing animals create spatial heterogeneity in plant growth conditions through selective grazing and nutrient transfer to preferred resting areas. The effect of such heterogeneity was assessed in a long-term low-input cattle grazing experiment in the Solling Uplands, Germany. Three paddock-scale grazing intensities were compared in three replications. Cattle grazing created a stable mosaic of vegetation patches: tall sward patches (mainly avoided by animals) exist together with short ones (frequently grazed). In a stratified sampling design, vegetation composition and soil nutrient concentration were assessed in short and tall patches (n = 210) along spatial gradients of animal behaviour. The effects of grazing intensity, patch differentiation and soil nutrient concentration on species richness, Shannon index, and Grime's plant strategy types were determined. Grazing intensity did not affect the assessed variables, whereas sward height class and soil nutrient gradient, singly and interactively, had significant effects. These findings highlight that sward structure and nutrient patterns, induced by grazing cattle, are more important than grazing intensity *per se* in driving plant diversity and dominant plant strategy types.

Keywords: livestock extensive management, patch-grazing, species richness, Shannon diversity index, Grime's strategy types, soil nutrient concentration

Introduction

Biodiversity conservation of grasslands is a challenge to current farming systems. Livestock grazing, as a sustainable management strategy, plays a key role in maintaining sward plant diversity. Grazing animals create spatial heterogeneity in plant growth conditions through selective grazing and nutrient transfer to preferred resting areas. In addition, they also create a mosaic of tall and short patches (referred to as 'patch-grazing' hereafter, Adler *et al.,* 2001). These vegetation patches, which are often stable in time (Tonn *et al.,* 2014), can be considered as the elementary units of such a grassland system. A better understanding of the dynamics occurring in grasslands would, therefore, be essential to find the best grazing practices to safeguard both plant biodiversity and sward productivity. This heterogeneity effect was already addressed by Wrage *et al.* (2012), however, a consistent analysis of the variability and the relationship with vegetation and soil nutrient concentration is missing. Furthermore, the influence of the grazing intensity at the paddock level on these aspects of sward structure heterogeneity has not been considered in any depth. Therefore, an ongoing long-term grassland experiment with grazing cattle was used to study the effects of grazing intensity, patch differentiation and the related nutrient transfer on target variables.

Materials and methods

A continuous grazing experiment with Simmental suckler cows was established in 2002 in the Solling Uplands in southern Lower Saxony, Germany, on a moderately species-rich *Lolio-Cynosuretum* grassland. Three grazing intensity treatments with three replicate paddocks of 1 ha each were compared. Treatments were based on different target compressed sward heights, corresponding to different stocking rates:

moderate (6 cm), lenient (12 cm) and very lenient stocking (18 cm target sward height). Long-term average stocking rates were 645, 360 and 245 kg ha^{-1} y^{-1}, respectively. Sward height was measured every two weeks and animal number was adjusted to maintain the target sward heights. Paddocks were grazed from early-May to mid-September. In all three grazing treatments, a stable mosaic pattern of tightly grazed short and of mainly avoided tall patches, had developed over time. Area proportion of patches increased from the moderate to the very lenient grazing treatments, i.e. sward structure was affected by the grazing intensity. In a stratified sampling design, botanical composition and soil nutrient concentration were determined in short and tall patches (hereafter sward height classes, SHC) along spatial gradients of animal behaviour. A total of 210 quadrats of 0.25 m^2 each were placed in short and tall patches in a paired design: 15, 20 and 15 pairs per paddock for moderate, lenient and very lenient stocking, respectively. In March 2017, soil samples were collected to a depth of 10 cm to assess CAL-extractable phosphorous (P), potassium (K) and $CaCl_2$-extractable magnesium (Mg). All vascular plant species and their estimated biomass percentages were recorded in June 2017. Vegetation diversity was expressed as species richness and Shannon index (H index, potential values 0 to 5; Magurran, 1988). Each plant species was classified according to its Grime's strategy type (Grime, 1979) using the BiolFlor database (Klotz *et al.,* 2002). Strategies having species biomass shares of less than 4% were not included in the analysis. The effects of grazing intensity, SHC and soil nutrient concentration on the assessed variables, both individually and interactively, were tested. The best fitting model was identified through the corrected Akaike Information Criterion.

Results and discussion

A total of 72 plant species (mean 11.2 ± 4.07 species per 0.25 m^2) were recorded, 29 of which displayed exclusively a competitive strategy (C), 24 an intermediate strategy (i.e. competitive-stress-tolerant-ruderal strategy, CSR) while nine showed a transitional type between competitive and ruderal strategy (CR). Model results (Table 1) did not show significant effects of the grazing intensity on any of the assessed variables, whereas SHC was always significant. The presence of C and CSR species was influenced by the availability of all the soil nutrients, while CR strategists were only affected by Mg. A significant

Table 1. Effects of the assessed variables on species richness, Shannon index and Grime's strategy type values resulting from the best fitted models. * = $P < 0.05$; SHC = sward height class; C = competitive strategy; CR = competitive-ruderal strategy; CSR = competitive-stress tolerant-ruderal strategy; - = variable not included in the best fitting model.

	Variables	Species richness	Shannon index	Grime's strategy types		
				C	CSR	CR
Soil magnesium	log (Mg)	0.0001*	0.8167	0.0261*	0.0421*	0.0004*
	Grazing intensity	-	0.1126	-	-	-
	Sward height class	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*
	Block	0.0182*	0.0040*	0.0157*	0.1102	0.0136*
	SHC × log (Mg)	0.0026*	0.0013*	-	0.0168*	-
Soil potassium	log (K)	0.0001*	-	0.0001*	0.0001*	0.7850
	Grazing intensity	-	0.1261	-	-	0.2185
	Sward height class	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*
	Block	0.0777	0.0051*	0.0093*	0.0664	0.0888
	SHC × log (K)	0.0486*	-	0.0312*	-	-
Soil phosphorous	log (P)	0.0001*	-	0.0001*	0.0001*	0.3815
	Grazing intensity	-	0.1261	-	-	0.1815
	Sward height class	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*
	Block	0.0893	0.0051*	0.0124*	0.0908	0.0687
	SHC × log (P)	0.0997	-	-	-	0.1406

interaction between SHC and soil nutrients was also detected. The short SHC had higher species richness and H index than the tall SHC ($P < 0.001$). Both diversity indices had a significant negative correlation with soil P and K levels, consistent with Paesel *et al*. (2017). Conversely, they displayed a significant positive correlation with soil Mg. However, considering soil K increase, species richness decreased only in tall and not in short sward patches. The high availability of soil K and P was related to tall and less defoliated patches, where species that are good competitors for light, i.e. species with a high proportion of competitiveness in their strategy (pure C or CR) increase their presence. Conversely, lower nutrient concentrations (apart from Mg) were found in short patches, where more species displaying at least a share of R strategy occurred. Under lesser nutrient availability and more frequent defoliation, stress-tolerating species were more abundant. A shift from nutrient to light limitation has been shown to be associated with species loss (Hautier *et al.,* 2009). Although Wrage *et al.* (2012), highlighted the significant effect of sward height on botanical composition, species richness and H index, they stated that soil nutrient availability was not a driving factor for phytodiversity. This plot-level study allowed a deeper analysis of the existing relationship between soil nutrients and vegetation variables. Further studies will investigate the relation between cattle spatial patterns and the observed soil nutrient gradients.

Conclusion

SHC and soil nutrient gradient, singly and interactively, affected the assessed variables, while grazing intensity did not. These findings highlight that sward structure (i.e. tall and short sward patches) and nutrient patterns, induced by grazing cattle, are more important than grazing intensity *per se* in driving plant diversity and dominant plant strategy types.

Acknowledgements

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'SiloExpert' – a model for predicting grass silage quality

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Abstract

On commercial farms, silage quality is determined several weeks or even months after ensiling or during feed-out. A Microsoft excel-based calculation sheet was developed for the on-farm prediction of grass silage quality immediately after filling the clamp or bale. The prediction is based on the crude protein (CP) and net energy of lactation (NEL) contents of the fresh grass before ensiling, its ensilability and the applied ensiling techniques. The model was tested in 16 silage production experiments on seven farms in northern Germany in 2015 and 2016. The measured NEL contents were compared with the predicted NEL contents. There was a high correlation between predicted and measured NEL content, as indicated by a R^2 of 0.93 and a modelling efficiency of 0.93. With the presented model, the farm manager has reliable information about silage quality for feed planning at a very early date.

Keywords: prediction, silage quality, silage bag experiment

Introduction

On commercial farms, silage quality is determined several weeks or even months after ensiling, based on laboratory analysis of the silage. However, earlier information about silage quality could improve the feeding strategy and help to better specify feeding rations. Based on original trials from the year 1983, 'SiloExpert' was developed to predict the crude protein (CP) and net energy of lactation (NEL) content of grass silage immediately after silo or bale filling. The model structure followed the approach described in the 'Normative Silokartei' by Weise and Rambusch (1988), and tested again on commercial farms in 2002 and 2004 (Pickert and Weise, 2014). Based on the test results and experiences, the model was implemented as a Microsoft excel-based calculation sheet. The objective of the present study was to revalidate the model in 16 trials on seven farms in Germany over two years to obtain findings for further development of the model towards an effective on-farm tool.

Materials and methods

'SiloExpert' requires the NEL content of the ensiled grass as an input as well as the ensiling conditions (Figure 1). The NEL content is determined at filling by laboratory analysis. The ensiling conditions depend on the ensilability of the grass and the ensiling techniques, which are evaluated by the model during filling. The ensilability of the grass is a function of many factors, e.g. DM content at ensiling and the use of silage additives and is affected by sward composition, mainly the proportion of *Lolium* spp. and legumes. The ensiling technique is mainly characterised by filling and compaction performance (Pickert and Weise, 2014).

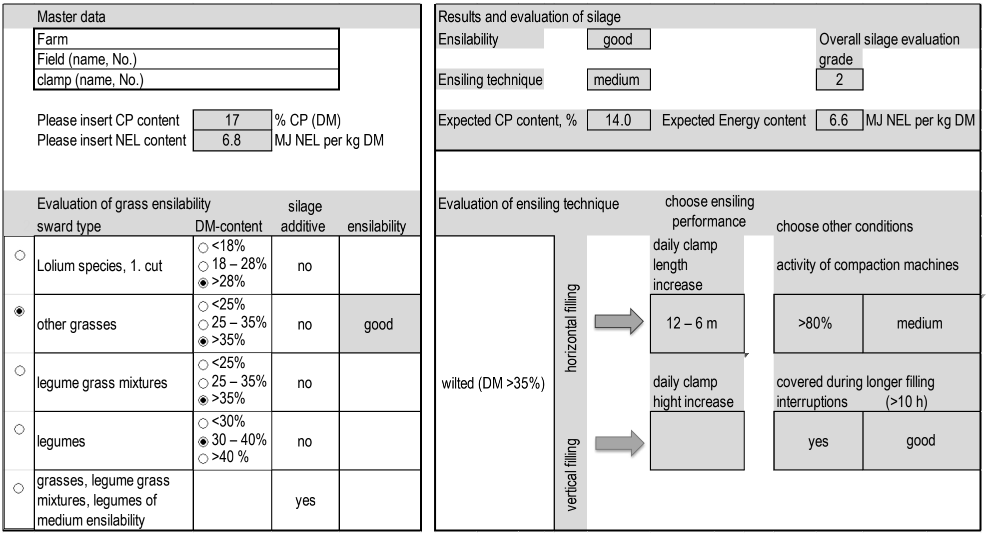

Figure 1. Data input and evaluation scheme of 'SiloExpert'.

All of the ensiling experiments were conducted within the conventional silage making procedure under the management of each farmer. Each ensiling experiment was conducted during filling either of horizontal silos (n = 12) or round bales (n = 4). In a horizontal silo trial, 12 samples were taken from the grass before ensiling, of which six samples (3 - 5 kg fresh matter) were immediately filled into six polypropylene tissue bags (60 × 30 cm) and ensiled in the silos. To assist recovery of the bags during feed-out, 3 m polyurethane tapes were attached to each bag. The remaining six samples were immediately analysed for NEL using NIRS (VDLUFA, 2012; DLG, 2013).

During the feed-out phase, the bags were removed from the silos and the NEL content was determined. In a silage bale experiment, the grass samples were each taken from the swath at the starting point of each single bale. The corresponding silage samples were taken from the center of the bale after opening for feeding. The information to manage and evaluate the ensiling technique was reported by the farmer. Measured silage NEL data were compared with the values predicted by 'SiloExpert'. The predictive ability of the model was quantified on the basis of the mean absolute error (MAE), the root mean square (RMSE) and the modelling efficiency (EF) (Nash and Sutcliffe, 1970).

Results and discussion

There was a high correlation between predicted and measured NEL contents, as indicated by a R^2 of 0.93 and an EF of 0.93. A MAE of 0.14 and a RMSE of 0.19 MJ NEL kg DM^{-1} revealed that the predictive ability of the model is suited for use on commercial farms (Figure 2).

The model provides the farmer with reliable information about silage quality at filling. Therefore, there is more time for feed planning, which is particularly important if poorer silage quality is indicated. As the places of origin for the different grass samples are in the model, the farm ensiling procedures can be accurately traced back up to the single field or sward and analysed in more detail in order to identify weaknesses.

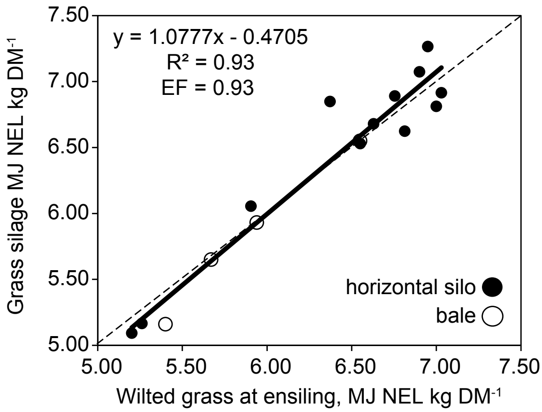

Figure 2. Relationship between NEL content of the grass silage and fresh grass at ensiling.

In some cases, particularly at higher NEL contents, the values determined for fresh grass were equal to, or even slightly less than, for the corresponding grass silage, which will require further investigations by forage analysis experts.

Conclusions

The 'SiloExpert' model provides reliable information about silage quality at a very early date with high prediction accuracy and has the potential for utilisation in practical farming. Since 2017, it is part of a European Innovation Partnership project (agrathaer, 2017), where it is applied with the support of the farm managers of seven commercial farms and developed into an on-farm management tool.

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Decomposition and nutrient release of winter annual forages in integrated crop-livestock systems

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Abstract

Information on residue dynamic is needed to synchronise nutrient release from cover-crop litter to cash-crop nutrient demand and to overcome potential deficiencies with appropriate fertilisation strategies in integrated crop-livestock systems (ICLS). We evaluated the influence of two ICLS (with and without trees) and two levels of nitrogen (N) fertilisation (90 and 180 kg N ha^{-1}) in winter pasture on the release rate of nitrogen, phosphorus (P) and potassium (K) from decomposing black oat (*Avena strigosa* Schreb.) / ryegrass (*Lolium spp.*) straw + tree components in a field experiment. Litter decomposition and nutrient release were assessed with litter bags placed at the soil surface in a randomised complete block with four treatments (two ICLS × two N levels) and with three replicates during the subsequent growth of corn for grain. During 165 days of decomposition, minor changes in N-P-K release dynamics were observed between treatments. However, total N-P-K released from winter residues and potentially available to the subsequent corn crop depended on the initial N-P-K level of residues and mainly on the quantity of plant residues.

Keywords: C_3 grasses, *Eucalyptus dunnii*, litter bag, corn, no tillage

Introduction

Globally, interest in integrated crop-livestock systems (ICLS) has been increasing due to their potential to achieve synergism and emergent properties as a result of soil-plant-animal-atmosphere interactions (Carvalho *et al.*, 2010). For instance, nutrient cycling is optimised when pastures and animals are incorporated in rotation with crops cultivated in no-tillage systems (Assman *et al.*, 2014). In ICLS typical of southern Brazil (summer cash crop / grazing cattle rotations) decomposition and nutrient release of winter annual forages could be affected by the resultant alterations in structure and quality of residues caused by nitrogen (N) availability and association with trees. However, little information is available to test this hypothesis. The objective of this research was to quantify decomposition and nutrient release of plant material from ryegrass (*Lolium multiflorum* L.) + black oat (*Avena strigosa* Schreb.) residue in two ICLS (with and without trees) with two N levels. By understanding these factors, ICLS managers can better manipulate the synchrony between nutrient release and nutrient absorption by subsequent crops.

Materials and methods

A field experiment was conducted in Southern Brazil (25°07'22"S, 50°03'01"W). In 2006, three tree species (*Eucalyptus dunnii, Schinus molle* and *Grevillea robusta*) were planted in six of 12 experimental units (e.u.), which ranged from 0.8 to 1.2 ha. The species were interspersed in the same rows at 3 ×14 m spacing (238 trees ha^{-1}). During the summer of 2013, the experimental area was thinned to 159 trees ha^{-1} by removing *Schinus molle* trees. Since winter 2010, the production system integrated cattle (Purunã beef heifers, see Pontes *et al.*, 2018 for more details) grazing on cool-season pasture (ryegrass + black oat, with a sward height of 20 cm using the 'put-and-take' method) and warm-season corn or soybean crops on the same area and in the same cropping year using no-till. The experimental design was a randomised complete block with three replicates. Two N levels in winter pasture (90 and 180 kg N ha^{-1}, or N90 and

N180, respectively) were crossed with two ICLS: crop-livestock only (CL) and crop-livestock with trees (CLT). The black oat + ryegrass mixture was sown at a seed rate of 45 and 15 kg ha^{-1}, respectively, in April 2013 and 400 kg ha^{-1} of commercial formula 4-30-10 (N, phosphorous (P) and potassium (K)) was applied. The stocking season began on 3 July. Heifers grazed until 8 October. Corn was sown in November 2013 (75,000 plants ha^{-1}, 80 cm row spacing) using 400 kg ha^{-1} of commercial formula 10-30-10 (N-P-K + 270 kg N ha^{-1} as urea, 40 days after sowing). Dry-matter decomposition was evaluated with litter bags placed on to the surface soil of the succeeding corn crop. Plant residue collected at the end of stocking season was used. Residue samples of 20 g were placed into 20 × 20 cm nylon-screen litterbags with 2 mm openings. A total of three litter bags were placed in each e.u., during corn sowing, for retrieval at 8, 15, 30, 60, 90, 120, 150 and 165 d of incubation. Litter bag contents were oven-dried (55 °C) for 48 h and weighed. Dry-matter decomposition and nutrient release were determined from weight differences and nutrient concentrations among incubation periods. Total N was analysed with the Kjeldahl method, P by colorimetry and K by flame photometry (Malavolta *et al.*, 1997). Data of DM, N, P and K remaining at each retrieval date were fitted to a non linear model for each e.u. to produce decomposition characteristics that were further analysed with analysis of variance. The exponencial model was: rem = res + act × e^{-kt} where, rem is remaining constituent (DM, N, P and K) after t (days); res is the size of a resistant fraction not showing signs of decomposition during 165 days, act is the size of an active fraction decomposing during 165 days, and k is a non-linear decay constant of the active fraction.

Results and discussion

The seven year old trees in our experiment significantly reduced the quantity of plant residue (Table 1). This result indicated that shade provided by trees in the CLT - as high as 41% (Pontes *et al.*, 2018) in relation to the open field - affected pasture growth. An increase in N application increased the initial N concentration in CLT treatments. No significant differences were observed between treatments for initial P and K concentration (Table 1).

The decomposition rate (k) changed significantly ($P = 0.044$) with treatments, ranging from 1.3 ± 0.56 (CLT N180) to 6.8 ± 1.26 (CL N90) mg $g^{-1}d^{-1}$. Consequently, days needed to decompose 50% of the initial residue (i.e. from active fraction) ranged from 11 (CL N90) to 54 (CLT N180). Dry matter decomposed slowly in CLT N180 treatment probably due to changes in sward structure, in the quantity and in the composition of the residue (e.g. 36% of the residue came from the trees, data not shown). Total N, P and K released from pasture residues (or pasture + tree residue for CLT system) for the corn crop were greatest in CL N180 treatment (Figure 1), mainly due to the greatest initial residue mass. The non-linear decay constant of P was significantly affected by treatments, ranging from 2.2 ± 0.45 (CLT N90) to 8.9 ± 3.4 (CL N90) mg $g^{-1}d^{-1}$. The non-linear decay constant of N and K did not change significantly with treatments, averaging 3.7 ± 0.70 and 5.4 ± 0.24 mg $g^{-1}day^{-1}$, respectively. Differences between treatments in the total N released from pasture residue and potentially available to the subsequent corn crop (Figure 1) also occurred due to changes in the initial N level.

Table 1. Initial residue from pasture and nutrients concentration for each treatment.

	DM (kg ha^{-1})	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})
CL N90	4,191 ± 848.0^{ab}	13.8 ± 0.53^{ab}	1.64 ± 0.17	12.9 ± 1.47
CL N180	5,018 ± 298.0^{a}	14.3 ± 1.13^{ab}	1.96 ± 0.10	14.5 ± 0.61
CLT N90	3,419 ± 343.8^{b}	11.8 ± 0.93^{b}	1.36 ± 0.13	11.7 ± 1.10
CLT N180	3,041 ± 146.0^{b}	14.4 ± 0.61^{a}	1.91 ± 0.19	13.6 ± 1.81
P	0.0212	0.0398	0.1372	0.7044

P = probability for the treatment effect. Within column, means followed by the same letter are not significantly different according to LSD test ($P < 0.05$). DM = dry matter; CL = crop-livestock; CLT = crop-livestock-trees systems; N90 and N180 = 90 and 180 kg N ha^{-1}, respectively. N = nitrogen, P = phosphorous, K = potassium.

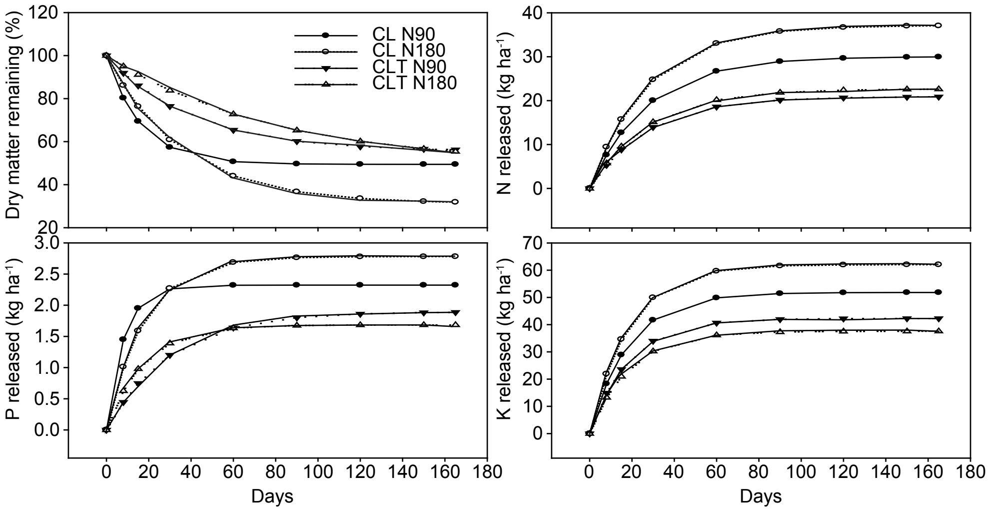

Figure 1. Dry matter remaining and nutrients released from stocking season residue (i.e. from pasture residue, *Lolium multiflorum* + *Avena strigosa,* or pasture + tree residue for tree systems) during litter-bag exposure in the field as affected by treatments. See Table 1 for treatment codes.

Conclusion

During 165 days of plant material decomposition, large amounts of N (37 kg ha^{-1}), P (2.8 kg ha^{-1}) and K (62 kg ha^{-1}) were cycled in a beef cattle-corn integrated system and must be considered in the fertilisation management. Silvicultural interventions (e.g. more frequent thinning) need to be intensified to reduce the shading level to below 41% and avoid losses to soil cover, which in turn, will maximise benefits from nutrient cycling.

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The effect of the partial replacement of grass silage with whole-crop silage on milk production

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Abstract

Mixtures of cereals with leguminous plants harvested as whole crops can provide cost-effective feed that combines as both an energy and protein supply. An experiment with 36 cows was conducted to investigate the effect of whole-crop silage on milk production and feed efficiency. The forage treatments were: Control (grass silage alone), Wheat (grass silage with whole-crop wheat (*Triticum aestivum* L.) in a 60:40 DM ratio) or Lupin (grass silage with whole-crop wheat and white lupin (*Lupinus albus* L.) silage in a 60:40 DM ratio). Diets were fed as total mixed rations (TMR). The energy content of whole-crop silages was low compared with grass silage. However, replacing grass silage partially with whole-crop silage increased intake, so the metabolisable energy (ME) intake of whole-crop diets was higher compared with the Control. There was no difference in milk production but feed efficiency (MJ ME kg^{-1} energy corrected milk (ECM)) was the highest with the Control. Lupin had no additional benefit compared with Wheat. The growing conditions were not favourable for lupin, and the proportion of lupin was only 180 g kg^{-1} in the whole-crop mixture. It can be concluded that grass silage can be partially replaced with whole-crop silage in dairy cow diets.

Keywords: dairy cows, feeding strategy, *Lupinus albus* L.*,* whole-crop

Introduction

The feed production strategy greatly influences the profitability of milk production. The most common forage in Finland is grass silage which is high, both in digestibility and in crude protein concentration. An alternative to this is low digestibility whole-crop silage (WCS) harvested at the dough stage. The advantage of WCS is the high DM yield and low production cost because of harvesting once per season. Wheat (*Triticum aestivum* L.) has been one of the highest yielding species among cereals (Kykkänen *et al*., 2016). Experiments conducted with barley or wheat whole-crop silage have shown comparable milk production between grass silage and WSC-silage mixtures (Jaakkola *et al*., 2009). However, there is a need for an experiment to ensure farmers will accept WCS as a feed for dairy cows. Recently, interest in grain legumes harvested as WCS has increased because of the capability to produce additional protein. Mixtures of cereals with grain legumes harvested as whole crops can provide cost-effective feed that combines both energy and protein supply. The objective of this study was to assimilate additional information about low-digestibility wheat whole-crop silage as a feed for dairy cows. The second objective was to evaluate whether the use of white lupin (*Lupinus albus* L.) can increase milk production compared with whole-crop wheat.

Materials and methods

The silages were produced at Luke's experimental farm in Maaninka, Finland, during the 2016 growing season. A second-growth sward of timothy (*Phleum pratense* L.) and meadow fescue (*Festuca pratensis* L.) was harvested on 17 July. Whole-crop wheat silage and a whole-crop wheat and white lupin silage were harvested on 18 and 24 August, respectively. The grass and whole-crop wheat were ensiled into bunker silos using a formic-acid-based additive at approximately 5.0 l t^{-1}. The whole-crop wheat and white lupin mixture was ensiled into round bales using the same additive as with the grass silage. The growing conditions were not favourable for lupin and the proportion of lupin was only 180 g kg^{-1} in the whole-crop mixture.

The forage treatments were Control (grass silage alone), Wheat (grass silage with whole-crop wheat in a 60:40 DM ratio) or Lupin (grass silage with whole-crop wheat-white lupin silage in a 60:40 DM ratio). Diets were fed as TMR with a target concentrate proportion of 450 g kg^{-1} including minerals. The concentrate in TMR contained barley at 800 g kg^{-1} and rapeseed meal at 200 g kg^{-1} on an air-dry basis. Cows also received 1.0 kg barley d^{-1} from a feeding station so the total concentrate proportion was 480 g kg^{-1}. The feeds were analysed (crude protein, *in vitro* organic matter digestibility, ash, neutral detergent fibre, fermentation quality) using the standard methods of Luke.

The experiment was conducted using 24 Holstein and 12 Nordic Red dairy cows. The average milk yield at the beginning of the experiment was 34.7 kg d^{-1} (s.d. 6.2 kg) and the cows were 78 days in milk (s.d. 24). Intake was measured using automatic feed bins (RIC system, Insentec). The experiment had an incomplete cross-over design with two periods. The transition time between the periods was 14 d and data collection lasted for 7 d. Data was analysed with the Mixed procedure in SAS. The model included the fixed effects of treatment, block and period. Animal was used as a random variable.

Results and discussion

The DM intake of WCS was 7% greater than that of grass silage. The preservation method was not the reason for the difference because the nutrient loss from wrapped bales is higher compared with bunker silos due to the high plastic covered area of bales (Wilkinson and Fenlon, 2013). Here, all types of silage were preserved well. The increased DM intake with whole-crop silages is in agreement with earlier results reported by Jaakkola *et al.* (2009). The increasing proportion of legumes should increase intake (McKnight *et al.*, 1977; Kuoppala *et al.*, 2009), but this hypothesis was not supported here because of the low proportion of lupin in the silage. The tiller density of lupin was adequate but bacterial inoculation was incomplete, resulting in a low lupin DM yield in the WCS. The crude protein content concentration of the Wheat and Lupin WSC was quite similar due to the low amount of lupin seeds in the crop. The neutral detergent fibre intake was lowest in Control (2.1 kg vs 2.3 kg for the whole-crop silage types), so rumen fill was not the limiting factor for Control DM intake.

There were no differences in milk yield or energy corrected milk (ECM) yield amongst the diets. This is in accordance with earlier results (Jaakkola *et al.*, 2009). Lupin provided no benefit compared with Wheat. Despite the control group having a slightly lower concentrate proportion, the metabolisable energy (ME) content of the diet was greatest in Control. The high intake of whole-crop silage types overruled this, resulting in the highest overall ME intake with whole-crop silage types. However, this was not reflected in milk yield and energy utilisation was highest with Control.

The cows on the experiment were mostly at the beginning of lactation and the metabolisable protein balance was about 10% below the theoretical requirement in all diets. This could be one reason for the lack of response to additional ME intake with whole-crop silage types. Jaakkola *et al.* (2009) also reported decreasing energy utilisation with an increasing amount of WSC. The decreased energy utilisation also could be an intrinsic feature of WCS. The crude protein content of the whole-crop diets was 152 g kg^{-1} DM, so nitrogen was not a limiting factor for microbial protein synthesis. The urea content of the milk varied between 195 mg l^{-1} and 224 mg l^{-1}, showing a reasonable relationship between nitrogen and energy intake.

The use of WCS has potential to limit the crude protein intake of cows to reduce the harmful impacts of nitrogen on the environment, leaching or ammonia emissions. Nitrogen efficiency was slightly higher with Wheat compared with Control. Due to the increased intake of WCS, the difference in nitrogen utilisation was quite small but it was an improvement in the right direction that had no adverse effect on milk production.

Table 1. Intake, milk production and energy utilisation of the experimental silage types.

	Control	Lupin	Wheat	SEM	Significance
Intake (kg DM d^{-1})					
Silage	11.1^a	11.1^a	11.6^b	0.19	< 0.05
Concentrate	9.9^a	10.8^b	10.9^b	0.12	< 0.001
Total	21.0^a	21.9^b	22.5^b	0.25	< 0.001
Metabolisable energy (ME; MJ)	243^a	258^b	259^b	3.05	< 0.001
Milk production (kg d^{-1})					
Milk	33.7	33.7	34.0	0.40	NS
Energy-corrected milk (ECM)	36.0	36.1	36.5	0.39	NS
Nutrient utilisation					
ME (MJ kg^{-1} ECM	4.90^a	5.25^b	5.28^c	0.102	< 0.01
kg ECM kg^{-1} DM	1.72^a	1.62^b	1.61^b	0.020	< 0.01
kl[1]	0.65^a	0.61^b	0.60^b	0.014	< 0.01
Milk nitrogen/nitrogen intake	0.35	0.36	0.36	0.006	NS

[1]kl = efficiency of utilisation of ME for milk production.

Conclusion

The partial replacement of grass silage with WCS increased ME intake but decreased ME utilisation, without affecting milk production. Whole-crop lupin did not have any advantage compared with whole-crop wheat. It can be concluded that grass silage can be partially replaced with whole-crop silage in dairy cow's diet.

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Tagasaste (*Chamaecytisus proliferus* var *palmensis*) feeding value and dairy sheep performance in a poor Sardinian soil

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Abstract

Tagasaste (*Chamaecytisus proliferus* Link var. *Palmensis* (Christ.) G. Kunkel) is a drought resistant perennial leguminous shrub well adapted to the Mediterranean environment and is utilised as a forage species in rainfed grazing systems. Eighteen randomly sampled plants of Tagasaste were studied in a 6,718 m^2 experimental area with 4,464 plant ha^{-1} on poor soils in the southern Sardinia (Italy). Shrub biomass production and plant structure were assessed monthly in winter and spring 2012. In this period, 30 mature Sarda dairy ewes were allowed to graze the area, when feeding value, secondary compounds content, biomass selected by ewes, milk production and quality were measured. In early winter, biomass was 1.4 t DM ha^{-1}. The growing period peaked in March when a branch increment of 41% in length and of 25% in weight was detected. In January, on average, 53% of branches' weight consisted of leaves. Nutritional value decreased during the season and twigs crude protein ranged between 238 g kg^{-1} (January) and 164 g kg^{-1} (June). A low content of formononetin and genistein were detected. In both grazing periods, sheep milk production showed an increasing trend. Tagasaste was highlighted as a potentially interesting complementary feed resource in Mediterranean dairy sheep systems, in particular, in drought marginal area and soils with severe limitations.

Keywords: leguminous shrub, forage resources, nutritive value, ewes, phytoestrogen

Introduction

In Mediterranean environments, hot dry summers and cool winters affect seasonal pasture production shortage. In rainfed grazing systems, spontaneous and cultivated woody species, such as evergreen shrubs, represent a forage resource that can integrate pasture production filling feed gap periods (Papanstasis *et al*., 2008). Tagasaste (*Chamaecytisus proliferus* Link subsp. *Palmensis* Christ. G. Kunkel) is a perennial leguminous shrub grown in a few drought areas and well adapted to the Mediterranean environment. It produces up to 12 t dry matter (DM) ha^{-1} $year^{-1}$ depending on crop location, grazing management and fertilisation (Assefa, 1998). Leaf proportion is a consistent part of the biomass yield, reaching up to 80%, depending on season and plant utilisation intensity (Assefa, 1998; Sulas *et al*., 2016). Tagasaste shows also a good nutritive value affected by season, plant parts, environmental and management conditions (Papanstasis *et al*., 2008; Sulas *et al*., 2016). The aim of this study was to assess seasonal productivity, chemical characteristics and nutritive value of Tagasaste crop grown in a Mediterranean marginal area and to test its effect on Sarda ewes' milk production.

Materials and methods

The study was conducted in a rainfed experimental Tagasaste crop (two years old, 6,718 m^2 and 4,464 plant ha^{-1}) located in the Southern Sardinia (Capoterra, Cagliari), in winter and spring 2012. Average annual precipitation and temperature are 452 ± 140 mm (1971-2000) and 17.7 ± 2.6 °C (1995-2014), respectively. In 2012, annual rainfall was 243 mm, much lower than the long term averages, whereas the annual medium average temperature was 17.8 °C, similar to the long term values (Data ARPAS). The soil is classified as clayey-skeletal, mixed, semi-active, thermic Ultic Palexeralf (USDA, 2014). Soil texture in the Ap and A2 horizons (50 cm depth) is sandy loam with average pH 5.6, low content of organic C 6.2 g kg^{-1}, total N 0.54 g kg^{-1}, assimilable P 10.0 mg $kg^{-1}$and exchangeable K 68.5 mg kg^{-1}, land capability class IV (AAVV, 2014). Three randomly sampled areas of six plants each were studied. Monthly

DM yield ha^{-1} was calculated by weighing dried twigs with leaves (edible biomass < 3mm of diameter) in five sample branches per plant and multiplying by the average number of branches per plant and plants per hectare. Moreover, in January, branch length was measured and plant structure was detected by partitioning branches in twigs and leaves. Twice, in January and in June, 30 mature Sarda dairy ewes grazed the Tagasaste crop, for a period of four days (7 h d^{-1}) each time, without receiving supplements. As a complement, the animals were allowed to graze on Italian ryegrass sward. During the grazing periods ewes were milked twice a day. Milk yield was recorded and milk composition (fat, protein, casein, lactose and urea content) was measured on three days out of four. In plants, crude protein (CP), NDF, ADF and ADL contents were measured using near-infrared reflectance spectroscopy (NIRS). Additionally, phytoestrogens were measured with TLC and HPLC methods. Data on twig chemical composition were analysed according to t-test with season as treatment and homogeneity of variances were verified using the Fisher test (SAS Institute, 2002).

Results and discussion

In early winter, biomass available was 1.4 t DM ha^{-1}. After first sheep grazing in January, Tagasaste plants showed a remarkable regrowth capability, reaching 2 t DM ha^{-1} in June when it was grazed again (Figure 1). The growth rate peaked in March when branches increased, on average, 41% in length and 25% in weight. In January, on average, 53% of edible DM biomass in branches consisted of leaves and 47% of twigs.

Nutritional value decreased from winter to spring (Table 1). The CP of twigs with leaves changed from 238 g kg^{-1} in January to 164 g kg^{-1} in June when ADF showed the highest values. In June, green pods that had 100 g kg^{-1} and 620 g kg^{-1} CP and NDF content, respectively, represented an additional seasonal feed source for animals. Phytoestrogen analysis highlighted low content of formononetin and genistein in the edible parts of the plant, 58 ± 6.12 and 1,716 ± 81.46 mg kg^{-1}, respectively (Cheeke and Shull, 1985). No coumestrol content was detected. Average milk yield was significantly higher in January than in June according to the normal lactation curve (Table 2). Sheep milk production increased from the first to the

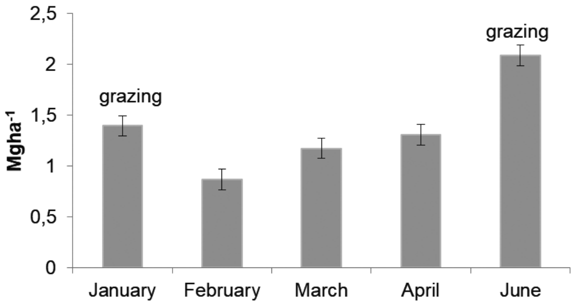

Figure 1. Biomass available (DM, Mg ha^{-1}) in Tagasaste crop in winter and spring 2012. In January and June biomass was grazed.

Table 1. Dry matter g kg^{-1} (DM), crude protein (CP), neutral detergent fibre (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) content (g kg^{-1} DM) in Tagasate twigs and pods in winter and spring.

Season	Twigs with leaves					Green Pods				
	DM g kg^{-1}	CP g kg^{-1}	NDF g kg^{-1}	ADF g kg^{-1}	ADL g kg^{-1}	DM g kg^{-1}	CP g kg^{-1}	NDF g kg^{-1}	ADF g kg^{-1}	ADL g kg^{-1}
January	304	238	388	207	64	-	-	-	-	-
June	388	164	391	242	60	710	100	616	389	78
P(t-Test)	<0.001	<0.001	ns	0.07	ns					

Table 2. Milk yield and chemical composition of sheep grazing Tagasaste (average ± se).

Season	Milk yield g $ewe^{-1}d^{-1}$	Fat g 100 ml^{-1}	Protein g 100 ml^{-1}	Casein g 100 ml^{-1}	Lactose g 100 ml^{-1}	Urea mg dl^{-1}
January	1,535 ± 16.45	7.7 ± 1.83	5.7 ± 0.14	4.55 ± 0.05	4.9 ± 0.09	44.4 ± 8.97
June	1,108 ± 59.90	7.6 ± 0.44	5.8 ± 0.12	4.56 ± 0.10	4.7 ± 0.06	36.3 ± 3.84

last day of grazing periods (4 and 29% in January and in June, respectively). Milk chemical composition did not change except for urea content that was higher in January as was plant CP content.

Conclusion

Tagasaste can be a feed source for ruminants in poor Sardinian soils, offering high seasonal DM production and good herbage quality. The plants have adapted to grazing and allowed the dairy sheep to maintain an average milk production and quality. Tagasaste could be included in Mediterranean dairy sheep systems to integrate pasture and rainfed forage crop productions, mainly in feed shortage seasons. Further studies need to evaluate the management systems to reduce the crop costs and to optimise the plant production performances.

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Agroforestry as a potential tool to mitigate climate change

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Keywords: agroforestry, climate change

Introduction

In 2014, FAO suggested five principles to guide strategic global development to provide 'a basis for developing national policies, strategies, programs, regulations and incentives that will guide the transition to an agriculture that is highly productive, economically viable, environmentally sound, and which is based on the principles of equity and social justice'. The first principle can be related to Agroforestry (AF). This paper aims to describe the main reasons linking AF and ecointensification.

Materials and methods

A review of main policies was undertaken to link AF and mitigation of climate change (Mosquera-Losada *et al*., 2016). This review was carried out under the FP7 EURAF AGFORWARD project.

Results and discussion

The first principle in dealing with the improvement of efficiency in the use of resources is crucial to sustainable agriculture. Agroforestry practices commonly enhance resource use in terms of the capture of solar radiation, water and nutrients at plot level. Hence, outputs per unit of land under AF are typically higher than under a monoculture arable crop or a monoculture tree crop. This increase in the capture of resources is called ecointensification.

Conclusion

Agroforestry is a sustainable way of ecointensification as it improves the use of resources (radiation, water and light) and, therefore, reduces the needs of external inputs in agricultural systems.

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Long-term effect of management on forage yield and botanical composition of an old pasture

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Keywords: legume, forbs, grassland, phosphorus, grazing

Introduction

Low input grassland system use is likely to be a central management strategy designed to maintain and restore the ecological diversity of semi-permanent grasslands. Potassium (K) application is very important to apply to pasture to increase the DM response of pasture to fertiliser (Whitehead, 1995). Fertiliser application enables farmers to influence pasture production. The objective of this study was to estimate DM stability and botanical composition of long-term pasture in relation to different long-term levels of K application.

Materials and methods

A long-term experiment was set up in 1961 on a loamy cultivated soil and continued until 2015. Plots were fertilised with different levels of K (0, 25, 50, 75 kg ha^{-1}) and phosphorous (P) (0, 26 kg ha^{-1}). Since the experiment was established, plots have been grazed using a stocking rate of 2 - 2.5 cows ha^{-1} y^{-1}. During the last ten years, experimental grassland was mown two - five times y^{-1}.The season started in May and lasted until October. The cut herbage was weighed and a 0.5 kg sample of the fresh herbage was taken to the laboratory for determination of DM and botanical composition. The botanical samples were measured after separation.

Results and discussion

After more than 50 years, DM yield was found to be positively affected by P and K. The differences between DM yield at the start and end of the decade of the experiment across all treatments were not very large (5.45 - 5.73 and 5.75 - 6.9 t ha^{-1}, respectively). It would be difficult to state very clearly the influence of K fertiliser based on the changes in DM over both periods of the experiment. Considerable differences in botanical composition were found between fertilised and non-fertilised plots. The results of the last ten experimental years indicate the relative importance of K. When pasture was mown in the last ten years, the botanical composition changed and legume content decreased by 4.8 - 5.4% of DM yield. Čop *et al.* (2009) recommended fertiliser application of either no fertiliser or 50 kg K ha^{-1} y^{-1}.

Conclusion

With regular application of P and K, it is possible to maintain a sufficient legume content (16.9 - 25.5% of DM yield) and a stable DM yield (6.0 - 6.9 t ha^{-1} y^{-1}) in long term grassland. Potassium applied at 50 kg ha^{-1} y^{-1} had an advantage over lower fertilisation levels.

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Amazing Grazing: science in support of future grass based dairy systems

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Abstract

The Amazing Grazing project addresses the challenges that Dutch farmers face in grazing systems with high feed supplementation and high stocking rates on the available grazing area. The project consists of six interlinked components (soil, grass growth, grass supply, grass intake, supplementation and behaviour), that are arranged around two grazing and three cutting experiments, as well as three farmer consultation groups. The grazing experiment showed that fresh grass intakes of approximately 6 kg DM cow^{-1} d^{-1} are feasible in intensive grazing systems with high feed supplementation levels. Tools for grass monitoring and planning, as well as cow behaviour monitoring, are being developed to support farmer decisions.

Keywords: Amazing Grazing, cow behaviour, planning, growth prediction, intake

Introduction

In the Netherlands, the proportion of dairy cows that had access to pasture declined steadily from 90% in 2001 to 65% in 2016 (CBS, 2017). The main driver of reduced grazing was increasing herd size combined with a lack of increase in the available grazing area (Van den Pol-Van Dasselaar *et al.*, 2013). Grazing is under debate amongst dairy farmers, the dairy chain and society. Several measures have been introduced to increase the proportion of cows having access to grazing. A crucial parameter that determines the ability to graze is the stocking rate on the available grazing area. Above a threshold of approximately 6 cows ha^{-1} it becomes increasingly difficult to maintain six hours of grazing per day. Consequently more farmers will be challenged to implement an efficient grazing system at these high stocking rates. The Amazing Grazing project addresses the issues that farmers face in managing grazing systems with high levels of feed supplementation.

Material and methods

The project framework (Figure 1) consists of six interlinked components (soil, grass growth, grass supply, grass intake, feed supplementation and cow behaviour) that are combined into three activities. (1) Two grazing experiments with contrasting grazing systems. On a clay soil, a Holstein herd grazed during day-time at a stocking rate of 7.5 cows ha^{-1}, either under Strip Grazing (SG) or Compartmented Continuous Grazing (CCG). On peat soil, a mixed Holstein and Jersey herd grazed at the same stocking rate, either under SG or Kurzrasen (KR). In SG, cows were offered a fresh strip of grass each day. Compartmented Continuous Grazing is an adapted set-stocking system in which the cows rotate on a daily basis between six compartments in one paddock. Kurzrasen is a set-stocking system with a target sward height of 3 to 5 cm. The non-exhaustive list of measurements comprised soil compaction measurements, sward height and density, *n*-alkane grass DM intake and cow behaviour using electronic sensors (Holshof *et al.*, 2018; Zom, 2018). (2) Cutting trials on clay, sand and peat soil with a combination of nitrogen (N) levels and growth intervals. Grass growth was measured with several nearby and remote sensing techniques based on spectral images. Short term growth predictions based on modelling and meteorological forecasts were compared to observed growth (Hoving *et al.*, 2018). (3) Three working groups of farmers, consultants and

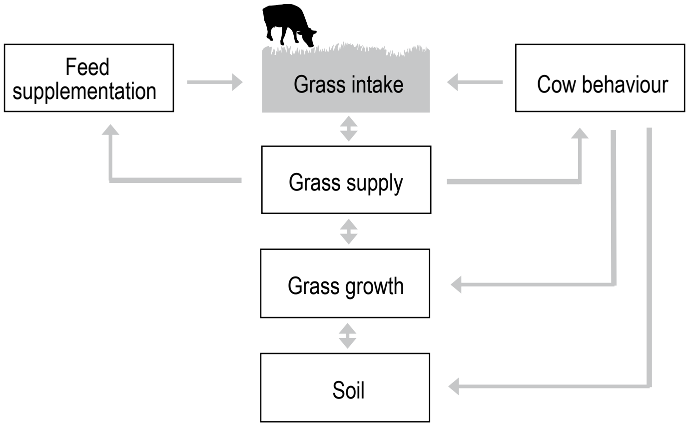

Figure 1. Framework of Amazing Grazing.

researchers, each focused on developing planning rules and tools for a different grassland management system (Stienezen *et al*., 2018).

Results and discussion

The grazing trials were carried out on perennial ryegrass (*Lolium perenne* L.) dominant (> 50%) swards. On peat soil, the sward density and carrying capacity was higher on KR than on SG. In the first year, fat and protein corrected milk production levels were 27 and 22 kg cow^{-1} d^{-1} on clay and peat soil, respectively (Table 1), with no treatment effect (Holshof *et al*., 2018). The daily supplementation levels per cow were 7.7 kg DM maize silage and 5.1 kg concentrates on clay soil, and 4.0 kg DM grass silage and 6.7 kg concentrates on peat soil. Based on the required energy intake, the proportion of Net Energy Lactation (NEL) from grass intake was around 30%. This equates to average daily grass intakes of 5 to 6 kg DM cow^{-1}. The daily time at pasture was 7.5 hours on clay soil (day-time grazing) and 12 hours on peat soil (night-time grazing). The average proportion of time spent grazing was 54 and 38% of pasture time on clay and peat soil, respectively, resulting in equal amounts of actual grazing time at both sites. On clay soil, the *n*-alkane grass intake during three weekly periods was 6.2 and 4.5 kg DM cow^{-1} d^{-1} on CCG and SG, respectively (Zom, 2018). Attempts to stimulate fresh grass intake by lowering rumen-degradable protein balance (OEB) in concentrates were unsuccessful, but reduced maize intake instead. The low OEB group produced less milk than the high OEB group, but the N utilisation increased from 35% to 40% (Klootwijk *et al*., 2018).

In the cutting trials, the biomass index WDVI (Weighed Difference Vegetation Index) showed a good exponential relationship with ground truth DM yield for individual cuts (Hoving *et al*., 2018). Short term predictions of grass growth were relatively successful for mineral soils, but rather poor for the peat soil because of the complex hydrology and soil N turnover.

Planning tools were developed for rotational grazing systems with high feed supplementation levels and implemented in a web application (Stienezen *et al*., 2018).

Table 1. System performance (2016) for day-time grazing (clay) and night-time grazing (peat). SG = Strip Grazing; CCG = Compartmented Continuous Grazing; KR = Kurzrasen.

	Clay soil		Peat soil	
	SG	CCG	SG	KR
Nitrogen input (kg ha^{-1})	358	356	175	175
Grazing season (h d^{-1})	192	185	163	181
Pasture time (h d^{-1})	7.5	7.6	11.6	12.9
Grazing (%)	52	55	37	38
Grazing time (h d^{-1})	3.9	4.2	4.3	4.9
Grass on offer (cm)	9.0	7.2	11.0	3.7
Residual sward height (cm)	5.4	6.1	6.4	-
NEL from grass intake (%)	26	33	29	33
Grass intake (kg DM cow^{-1} d^{-1})	5.1	5.4	6.1	-
Grass silage intake (kg DM cow^{-1} d^{-1})	-	0.2	4.3	3.6
Maize silage intake (kg DM cow^{-1} d^{-1})	7.5	7.8	-	-
Concentrates intake (kg DM cow^{-1} d^{-1})	5.0	5.1	6.7	6.7
Milk production (kg FPCM cow^{-1} d^{-1})	26.6	27.7	22.3	22.0
Animal weight (kg)	618	612	487	489
Silage yield (kg DM ha^{-1})	3,629	1,595	1,602	838

Conclusion

The grazing experiment showed that daily grass intakes of approximately 6 kg DM cow^{-1} are possible in intensive grazing systems with high supplementation levels. At least two thirds of the total grass DM yield was fresh herbage intake. Tools for grass monitoring and planning, as well as cow behaviour monitoring, are being developed to support farmer decisions.

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Contribution of urine spots to yields and nitrogen efficiency in pastures with different nitrogen fertilisation

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Abstract

In dairy farming, organic manures are an important source of nitrogen (N). Nitrogen return to grazed grasslands is mainly by slurry and by urine spots. The high concentrations of N in urine spots can lead to large N losses, but can also contribute to the herbage yield. To investigate the effect of N from slurry and mineral fertiliser on herbage N concentration, DM yield, and overall N efficiency, we set up a field experiment with five treatments of N fertilisation (control, slurry: 120 and 240 kg N ha^{-1}; slurry and mineral N: 240 and 360 kg N ha^{-1}). Grazing was simulated by cutting and subsequent N return via artificial urine spots with fixed N concentration and size - set at 73% of harvested N. Overall N concentration of the sward increased with N input and proportion of mineral N. Accumulated yields at an input of 240 kg N ha^{-1} from slurry and mineral N (120/120) were higher than those from slurry only; an input of 360 kg N ha^{-1} (240/120) did not lead to a further increase in yield. Apparent N recovery was highest at 240 kg N ha^{-1} when slurry and mineral N were combined. In order to improve N utilisation, urine spots need to be taken into account.

Keywords: pasture, nitrogen fertilisation, urine spots, nitrogen efficiency

Introduction

In dairy farming nitrogen (N) losses are a growing problem. Nitrogen losses in dairy farming occur because of an imbalance between a low N-output in milk and meat and a substantial N-input in the form of purchased concentrated feed and mineral N fertiliser (Aarts *et al.*, 1999). During grazing up to 85% of the N intake will return to the pasture (Whitehead, 1995). Most of the N is recycled through urine spots and the N return depends mainly on stocking rate and, therefore, affects grass on offer and corresponding N supply. Generally, a higher N-concentration in grass and feed leads to a higher concentration of N in urine spots (Ledgard, 2001). Within the pasture, urine spots are places with a locally very high N content which can result in nitrogen losses in the form of ammonia (NH_3), nitrous (N_2O) and leaching of nitrate (NO_3) (Moir *et al.*, 2010). To investigate the effect of N from slurry and mineral fertiliser on N cycling in pastures, we set up a field experiment with five treatments differing in form and amount of N fertilisation. We simulated grazing by frequent cutting and subsequent N return via artificial urine. Our hypothesis is that N recycling and N efficiency of urine spots is affected by form and amount of N fertilisation.

Materials and methods

The experimental site was located in Cloppenburg, Lower-Saxony in northwest Germany (52°56'44" N, 7°50'17" E) and is six meters above sea level. The average temperature is 8.7 °C and the average annual rainfall is 786 mm. The three year grassland ley was based on a ryegrass (*Lolium perenne* L.) dominated mixture with no clover. The experiment consisted of five treatments replicated in four blocks; plots were 12 × 1.5 m in size. The different fertilisation treatments with levels from 0 to 360 kg N ha^{-1} with cattle slurry and mineral fertiliser (calcium ammonium nitrate - CAN) are listed in Table 1. We present data from the first experimental year (May to October 2016).

Table 1. Different fertilisation treatments of the plots (n = 4) with slurry alone (SLR) or a combination of slurry and mineral N (SLM), mineral N as CAN; the number following SLR or SLM denotes the total amount of N; the total N-input is the sum of N from fertilisation and N return via artificial urine spots (see explanation in text and Table 2).

Treatment	N-fertilisation (kg ha^{-1})		Total N-fertilisation (kg ha^{-1})	Total N-input (kg ha^{-1})
	Slurry	Mineral N		
1 Control	0	0	0	85
2 SLR120	120	0	120	260
3 SLM240	120	120	240	492
4 SLR240	240	0	240	436
5 SLM360	240	120	360	631

In order to simulate grazing, the sward was mown six times and grab samples were taken from each plot. Herbage was oven-dried at 60 °C (> 24 hours), ground to < 1 mm, and analysed for N concentration (element analyzer, Heraeus) and DM at 105 °C. Following Whitehead (1995), we defined that 73.3% of the N harvested on each plot should be returned immediately after each cut as artificial urine in the form of simulated urine spots. The artificial urine was made up of water, urea, potassium bicarbonate, potassium chloride and sodium sulfate (Whitehead, 1970). Urine was poured in PVC tubes with a diameter of 40 cm (0.125 m^2) that had been inserted in the ground for 2 cm. The position of each urine spot was randomly chosen within a defined pattern of 72 squares in each plot. The N input at each spot was set at 10 g N which corresponded to 800 kg N ha^{-1}. The number of urine spots is, thus, a direct effect of harvested N. Dry matter yield and N-concentration were used to calculate the N-yield. For evaluating the N-efficiency, we calculated the N use efficiency (NUE), the apparent N recovery (ANR), the apparent N efficiency (ANE), and the number of urine spots per kg of N fertilisation (Table 2). For the calculation of ANR and ANE, we used the DM and N-yield from control plots of an adjacent experiment (cutting-only) with 0 kg N ha^{-1} and 0 urine spots. These control plots were mown four times with a DM-yield of 6,260 kg ha^{-1}, an N-yield of 114 kg ha^{-1} and an N-concentration of 1.8%. For statistical analyses we used an ANOVA with a post-hoc Tukey test to compare means (Genstat).

Results and discussion

Dry matter yields, N-concentrations of the herbage and corresponding N-yields were between 4,830 kg ha^{-1}, 2.3% N, and 112 kg N ha^{-1} for the control and 11,380 kg ha^{-1}, 3.2% N and 367 kg N ha^{-1} for SLM360 (Table 2). The number of urine spots, the DM-yield, the N-concentration and the N-yield of the SLM240 treatment with 120 kg N ha^{-1} from slurry and from CAN were higher than in the SLR treatment with 240 kg N ha^{-1} from slurry alone ($P < 0.1$). In this respect, values for SLM240 were not significantly lower than those for the SLM360 treatment which had received 120 kg N ha^{-1} more (Table 2). If we consider N input from slurry alone, we find that the yield increases with N input up to 240 kg N ha^{-1} (Control < SLR120 < SLR240). The nitrogen use efficiency (NUE; Table 2) is highest for the Control and lowest in the SLM360 plots; NUE decreased with N input. This shows that the 14 urine spots in the Control treatment had a strong effect. When N fertiliser was applied, the combination of 120 kg N from slurry with 120 kg mineral N per ha^{-1} (SLM240) had the highest efficiency with 70% compared to 61 and 58% for SLR240 and SLM360, respectively. Also, the ANR and the ANE (Table 2) were highest for SLM240 as was the number of urine spots per kg N (Table 2). Apparent N efficiency is rather low but ANR below 50% have also been reported by Haynes and Williams (2000). Lantinga *et al.* (1987) found no further increase in production beyond a fertiliser input of 200 kg ha^{-1} in pastures. In the current experiment there was no further increase in DM yield when an additional 120 kg N from slurry was applied (SLM360) to the level of 240 kg N ha^{-1} (SLM240).

Table 2. The number of placed urine spots (10 g nitrogen (N) per spot) based on DM yield and the N-concentration; N-yield and different parameters for N efficiency: N use efficiency (NUE) ((N-yield / N-input)*100); apparent N recovery (ANR) (($N\text{-yield}_x$ - $N\text{-yield}_0$) / N-input*100), apparent N efficiency (ANE) (($DM\text{-yield}_x$ - $DM\text{-yield}_0$) / (N-input)*100) and the number of urine spots (US) per kg N-fertilisation; all averaged over four replications. Means with different letters are significantly different ($P < 0.05$).

Treatment	Number of urine spots	DM-yield ($kg\ ha^{-1}$)	N-yield ($kg\ ha^{-1}$)	N-concentration (%)	NUE (%)	ANR (%)	ANE (%)	US per kg N
1 Control	14[a]	4,830[a]	112[a]	2.3[a]	132[d]			
2 SLR120	24[ab]	7,510[b]	190[ab]	2.5[ab]	73[c]	29	10	0.20[b]
3 SLM240	42[cd]	11,160[cd]	345[c]	3.1[cd]	70[bc]	47	13	0.18[b]
4 SLR240	33[bc]	9,530[c]	266[b]	2.8[bc]	61[ab]	35	11	0.14[a]
5 SLM360	46[d]	11,380[d]	367[c]	3.2[d]	58[a]	40	10	0.13[a]

Conclusion

The N recovery (ANR) and N efficiency (ANE) for simulated grazing with artificial urine spots was highest at a moderate N fertilisation level and when slurry and mineral N were combined (SLM240). The efficiency of N from urine spots differs among the fertilisation levels; contribution of urine-N to yield is substantial. We conclude that when N efficiency in grazed systems is to be improved, urine spots need to be considered.

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Prediction of breeding values and variance in (*Lolium perenne* L.) breeding populations

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Abstract

Perennial ryegrass (*Lolium perenne* L.) is the most important forage crop in temperate grassland agriculture, but acceleration of the rate of improvement of genetic gain is desirable. Genomic selection (GS) has the potential to achieve this, but prediction accuracies need to be sufficiently high to compete with phenotypic selection. Here we report the results of the performance of GS in the breeding programme at the Institute of Biological, Environmental and Rural Sciences (IBERS) using data from more generations than previously possible. Cross validation analysis showed that the highest prediction accuracies were obtained for dry matter digestibility (0.84) and water soluble carbohydrates (0.82). The accuracies for yield related traits ranged from 0.3 to 0.55. All accuracies represent an improvement on previous results. We also used the data to obtain predictions of the breeding values and their variance of all pairwise crosses of the population. Such data are likely to be helpful in deciding selections for variety generation and the population improvement cycle. The available variance is more important to preserve for the improvement cycle, while the highest possible combination of breeding values is needed for variety generation.

Keywords: *Lolium perenne* L., breeding, genomic selection, prediction accuracy

Introduction

Perennial ryegrass (*Lolium perenne* L.) is the predominant forage crop in temperate grassland agriculture. Reasons for this include its high digestibility, response to nitrogen fertilisation and persistency under grazing (Wilkins and Humphreys, 2003). Breeding diploid perennial ryegrass for forage is usually done using some form of recurrent selection. Quite often the selection is based on phenotypic data from plots of half-sib progeny. The mother plants may have been selected from spaced plant nurseries. The rate of genetic gain in biomass yield for example has been relatively slow (Conaghan and Casler, 2011). This has been attributed to low correlation between spaced plant and sward based performance for yield and persistency in particular, the need to breed for a large number of traits, and no harvest index to breed for (Casler and Brummer, 2008). Variety development is usually based on population improvement due to the outbreeding lifecycle of perennial ryegrass (Conaghan and Casler, 2011).

The perennial lifecycle contributes to the long breeding cycle of grasses. Genomic selection (GS) represents an option which can help to increase the rate of genetic gain in perennial ryegrass (Hayes *et al.,* 2013). The perennial ryegrass breeding programme at IBERS is suited to the implementation of a GS assisted approach to breeding, and the first assessment of this was reported by Grinberg *et al.* (2016). The results showed low prediction abilities for biomass yield, but higher for quality traits such as digestibility and water soluble carbohydrates. These results were based on a relatively small training population (364). Since then, the breeding programme has progressed, and this has expanded the training population size to 820. Here we report on updated prediction abilities based on cross validation, and on the prediction of breeding value and variance of crosses and their potential use.

Materials and methods

The IBERS diploid perennial ryegrass breeding programme was described previously (Grinberg *et al.,* 2016). The phenotypic data were obtained from plot trials of half-sib families derived from mother plants with the highest seed yield in a poly-cross of selected plants from a spaced plant nursery. Data from 820 half-sib families from seven generations, stretching over the period between 2001 and 2017, were used. Yield data were available for all families, while forage quality data were available for almost 700 families. Genotype data were obtained from mother plants of all 820 families. An Illumina iSelect array with 3000 validated SNP markers was used as described (Blackmore *et al.,* 2015; Grinberg *et al.,* 2016). Prediction abilities, expressed as the average Pearson's correlation coefficient between the genomically estimated breeding values (GEBV), and the observed phenotype, were obtained by cross validation (CV) using the rrBLUP model (Endelman, 2011). The fraction of the training population used for training was 0.8, sampled randomly 100 times, and the remainder was the validation set. GEBV and variances of pair-wise crosses were also obtained using the rrBLUP model. Both CV and cross prediction analyses were performed using the R package 'PopVar' (Mohammadi *et al*., 2015).

Results and discussion

The highest prediction accuracies were recorded for the quality traits, particularly WSC and DMD, while the accuracies for the yield data were lower (Table 1). Accuracies for all the traits were higher compared to those obtained by Grinberg *et al.* (2016). This could be explained in part by the larger training population now available, but also that the data presented here are based on CV, not on predictions of phenotypes not known by the model. Five other models were also tested, but none of them outperformed rrBLUP (data not shown).

Given the importance of knowing breeding values from crosses, we attempted to make predictions of breeding values and their variance based on the marker data, and the rrBLUP model, using 'PopVar'. The programme is designed for crosses between pairs of inbred lines. In the IBERS perennial ryegrass breeding programme multi-parental crosses are usually performed. Nevertheless, each seed is a product of two parents, so it may still be useful to be able to predict the possible pairwise combinations derived from the mother plants in any given generation. The simplest situation arises in variety generation where a poly-cross between four parents is performed. The highest possible combined breeding value would be desired for those, while there would be less need to preserve the maximum variance. For the population improvement cycle however, the aim would be to preserve as much variance as possible without compromising the phenotypic means. Figure 1 shows the predicted mean and variance for six traits of all pairwise crosses among the 54 mother plants of the F13 generation. The data points highlighted in purple shows the positions of one mother plant, which was selected to provide half sib progeny for the next generation of spaced plant trials. The figure shows that for all the traits except N, the progeny is likely to be at the high end of mean breeding value, and with a wide range of variances.

Table 1. Prediction accuracies and their standard deviations for seven traits in the IBERS perennial ryegrass breeding programme. N: nitrogen, WSC: water soluble carbohydrates, DMD: dry matter digestibility, NDF_DIG (phenotypic data available for 375 families): neutral detergent fibre digestibility, Total Yld: Total yield Year 1, Cons Yld: Conservation cut yield Year 1, Veg Yld: Vegetative yield Year 1.

Model	N	WSC	DMD	NDF_DIG	Total_Yld Y1	Cons_Yld Y1	Veg_Yld Y1
rrBLUP	0.63 ± 0.05	0.82 ± 0.03	0.84 ± 0.03	0.47 ± 0.08	0.33 ± 0.07	0.30 ± 0.08	0.55 ± 0.06

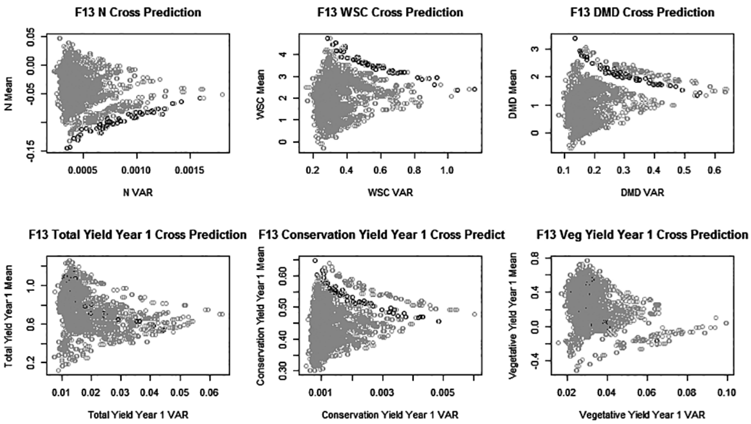

Figure 1. Prediction of breeding value and variance for six traits in all possible pairwise combinations of the F13 generation. Data for one mother plant is highlighted in purple.

Conclusion

Prediction abilities of IBERS perennial ryegrass breeding populations were high for quality traits, but lower for yield-related traits. The rrBLUP model performed similarly to five other models tested. Prediction of breeding values and variances of progeny from crosses showed that useful information can be derived from such data in terms of selecting the best parents for variety generation or the next cycle of the population improvement.

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Combined management of white and red clover for forage and seed production

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Abstract

White clover (*Trifolium repens* L.) cv. Atoliai, early tetraploid red clover (*Trifolium pratense* L.) cv. Vyliai, late tetraploid cv. Kirsinai and diploid cv. Arimaiciai were evaluated to test the possibility of using the crops for both forage and seed production. The clover was used for two years. In the first year of use Atoliai was left for seed or cut for forage three, four, five times. The red early clover Vyliai was cut two, three, four times, late Kirsinai and Arimaiciai were cut one, two, three times. In the second year of use clover was left for seed. In the first year of use the highest content of dry matter and metabolisable energy was obtained when white clover was cut for forage three-four times and red clover two-three times. Spraying with Ronilan in the autumn of the sowing year increased the winter survival of red clover Arimaiciai, which resulted in increased yields. White clover and red clovers produced a higher seed yield in the first year of use compared with the second year of use. A significantly higher seed yield was obtained in the second harvest year in treatments that had been cut for forage four to five times (white clover) or two to three times (red clover).

Keywords: clover, cutting frequency, forage, seed production

Introduction

Red clover is usually harvested for seed production in the first year of use. Such swards are productive and, during periods of heavy rainfall, are subject to lodging. For this reason combined management of clover (for forage and seed production) is often used (Medeiros and Steiner, 2000). The first crop of early red clover is often taken for forage, while the second crop is taken for seed production. White clover can be grazed-off early in spring, and after re-growth can be left for seed production (Frame, 2005). The advent of the new varieties has extended the longevity of red clover with late red clover persisting in the sward for three-four years. Due to their high forage production the seed yield is usually low in the first year and consequently a combined management of white clover and red clover was used in our research. In the first year of use clover was cut for forage and seed and in the second year of use only the seed was taken. Unfortunately, clover often thins out in the first year of use due to an inappropriate cutting regime or due to various diseases (Steiner &Alderman, 1999). In Lithuania this often happens due to Sclerotinia rot (*Sclerotinia trifoliorum* Erikss). With a view to extending red clover persistence in the sward we studied the efficacy of the fungicide Ronilan against Sclerotinia rot. The present study was conducted to determine the possibility of using the white and red clovers for both forage and seed production.

Material and methods

Our tests involved the early tetraploid red clover cv. Vyliai, late tetraploid red clover ('single cut') cv. Kirsinai, diploid red clover cv. Arimaiciai and large-leaved white clover cv. Atoliai. In the course of five years, trials were newly established three times. The experiment was designed as a randomised complete block with four replications and a plot size of 2.5×14 m. The soil of the experimental site was characterised as endocalcari-endohypergleyic cambisol, light loam. The soil characteristics were as follows: pH 7.0, mobile P - 93 mg kg^{-1}, and K -116 mg kg^{-1}. The clover was sown in spring with a cover crop of barley. The experiments with red clover cv. Arimaiciai were conducted under two spraying treatments: (1) Sprayed with the fungicide Ronilan 1 kg ha^{-1} in the autumn of the sowing year and (2) Unsprayed. The other clovers were sprayed with Ronilan throughout the whole experimental plot. The stands were used for two years. In the first year of use clovers were left for seed from the first and second crop or cut for forage (Table 1). The first crop of early red and white clover was harvested for forage on the first days of June. Early red clover was cut twice during the full flowering stage, three times at the beginning of flowering and four times at the full budding stage. Late red clover was left for seed from the first crop or cut for forage one, two, three times. Clover was cut once at mass flowering stage, twice at the beginning of flowering stage, and three times at the stage of mass budding. In the second year of use the seed was taken from the first crop (cv. Kirsinai, Arimaiciai) or the second crop (cv.Vyliai, Atoliai) in all treatments. The seed was combine-harvested. For the assessment of forage quality, chemical analyses of dry matter were performed for: crude protein, by determining the amount of nitrogen and multiplying by 6.25, crude fibre by the Hennerberg-Stohmann method, crude fat by the Rushkovski method, crude ash, by combustion. The differences in metabolisable energy were calculated on the basis of the chemical composition of DM, using digestibility coefficients and full value coefficients. The experimental data (herb dry matter yield, metabolisable energy, digestible protein) were processed by the method of analysis of variance, applying the ANOVA procedure.

Table 1. Annual dry matter yield, metabolisable energy (ME), digestible protein and seed yield of white clover and red clover (averaged data from three trials).

Sward use in the first year		DM yield ($t\ ha^{-1}$)	ME ($GJ\ ha^{-1}$)	Digestible protein ($kg\ ha^{-1}$)	Seed yield ($kg\ ha^{-1}$)	
					1st year use	2nd year use
White clover cv. Atoliai	1st crop for seed				266	110
	1st for forage- 2nd for seed	0.97	11.44	191	259	104
	Three cuts	4.46	48.33	715		99
	Four cuts	4.39	47.60	721		107
	Five cuts	3.95	44.40	697		125
	$LSD_{0.05}$	0.21	2.20	32		7.8
Red clover cv. Vyliai	1st crop for seed				103	114
	1st for forage- 2nd for seed	2.64	27.81	383	175	123
	Two cuts	7.26	71.64	770		137
	Three cuts	7.22	73.61	888		101
	Four cuts	6.59	70.66	986		101
	$LSD_{0.05}$	0.41	4.06	48		12.1
Red clover cv. Kirsinai	For seed				127	96
	One cut	6.50	60.76	552		79
	Two cuts	6.30	61.62	655		73
	Three cuts	6,95	70.50	862		112
	$LSD_{0.05}$	0.25	2.49	28		12.3
Red clover cv.Arimaiciai sprayed with Ronilan	For seed				208	189
	One cut	6.58	61.62	547		161
	Two cuts	6.78	66.41	779		166
	Three cuts	6.84	69.71	882		216
Red clover cv. Arimaiciai not sprayed with Ronilan	For seed				224	163
	One cut	6.14	56.73	478		148
	Two cuts	6.47	63.30	822		142
	Three cuts	6.46	65.88	767		191
	$LSD_{0.05}$	0.28	2.72	38		12.8

Results and discussion

In the first year white clover had the highest dry matter and metabolisable energy yield in the treatments cut three-four times (Table 1). In the treatments involving five cuts a significant yield reduction was recorded. The yield of digestible proteins was similar in all treatments 697-715 kg ha^{-1}. The highest dry matter yield of the red clover Vyliai was obtained in the treatments cut two-three times, whereas the highest metabolisable energy yield was produced in the treatments cut two-four times. The late-maturing clover Kirsinai gave the highest dry matter and metabolisable energy yield when cut three times, and Arimaiciai cut two-three times. The spray application of Ronilan in the autumn of the sowing year resulted in a significant improvement in the over winter survival of Arimaiciai, and in the first year of use in an increase in dry matter, metabolisable energy and digestible protein yield. Averaged data from three trials suggest that in the first year of use white clover Atoliai yielded 259-266 seed kg ha^{-1}, red clover Arimaiciai 208-224 seed kg ha^{-1}, Kirsinai seed 127 kg ha^{-1}, Vyliai 103-175 seed kg ha^{-1}. All cultivars used produced a higher seed yield in the first year of use compared with the second year of use. Clover persistence in the sward is to a great extent dependent on the time and number of cuts in the year of use (Taylor and Quesenberry, 1996). Ronilan spray application in the autumn of the sowing year gave a significant seed yield increase of Arimaiciai in the second year of use. A significant seed yield increase in the second year of use was obtained when in the first year white clover was cut four-five times, red clover Vyliai – two times, Kirsinai and Arimaiciai – three times. The highest relative profit based on seed yield and overall DM production was obtained when white and red clovers were left for seed in the first and second year of use.

Conclusion

White and red clover can be used under combined management, i.e. for forage and seed production. In the first year when clover was used for forage, the highest dry matter yield was obtained with three-four cuts for white clover and with two-three cuts for red clover. White clover and red clovers produced a higher seed yield in the first year of use compared with the crops of the second year of use. In the second year of use the seed yield was significantly higher when in the first year clover had been cut for forage at the following frequency: white clover Atoliai four-five times, early red clover Vyliai two times, late Kirsinai and Arimaiciai – three times. To prevent the spread of Sklerotinia rot, it is advisable to spray the fungicide Ronilan at a rate of 1 kg ha^{-1} in the autumn of the sowing year.

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The effect of Stymjod, an organic-mineral fertiliser, on *Trifolium pratense* L. biomass

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Abstract

The aim of the experiment was to study the effect of Stymjod, an organic-mineral fertiliser, on *Trifolium pratense* L. biomass. As the name indicates, Symjod contains 0.0025% of iodine (I). Apart from macronutrients and other micronutrients, the fertiliser consists of 56.8% organic matter. The experiment was carried out in a controlled environment, in a phytotronic room, with plants grown in pots. The fertiliser was applied twice, at the first node stage and at the ninth node stage. The following experimental combinations were used: F0 - control with plants sprayed with distilled water, F1 - plants sprayed with 1.5% solution of the fertiliser, F2 - plants sprayed with 3% solution of the fertiliser, F3 - plants sprayed with 4.5% solution of the fertiliser. The results were statistically processed, using Analysis of Variance. Tukey's test was used to find means that were significantly different. Standard Error was calculated to find out how the values spread, while the Statistica 6 program was used for all data analysis. The application of Stymjod resulted in a higher number of stems and leaves and an increase in the mass of the fresh matter of stems and leaves. Some parameters responded differently to different concentrations of the fertiliser. Plants treated with 1.5% solution had the biggest root system, while the mass of 100 leaves was the greatest when 4.5% solution was applied.

Keywords: biomass, plant, iodine, fertiliser, concentration

Introduction

According to the producer's information (http://www.phu-jeznach.com), Stymjod is a product made with nanotechnology, containing easily available mineral and organic nutrients positively affecting plant growth and development. The Stymjod production process is based on ionizing aqueous solution of a mixture of organic and inorganic components containing sulphur compounds with iodine, potassium, magnesium, the amide form of $CO(NH_2)_2$. Stymjod contains optimal levels of macronutrients, micronutrients and active iodine ions. They all activate cell metabolism, resulting in intense growth and development of plants and in increased resistance to adverse biotic and climatic conditions. In addition, biofortification of plants with iodine stimulates other metabolic processes, such as protein synthesis or the activity of enzymes and coenzymes. The fertiliser also contributes to an increase in resistance to fungal diseases (phenylalanine degradation), activates phosphorylation which normalises defensive reactions against stress and limits the flow of nutrients from the plants to the parasite and vice versa. At the same time, iodine accelerates regeneration of damaged tissue by stimulating anionic peroxidase which induces the synthesis of lignin and polysaccharides (Yamaguchi *et al*., 2006; Strzetelski *et al*., 2010; Smoleń *et al*., 2011). The aim of the study was to determine the effect of Stymjod, an organic-mineral fertiliser on the development of *Trifolium pratense* L. biomass. The experiment was carried out to determine whether a double spray of plants with Stymjod, with different concentrations, contributed to an increase in shoot and leaf number, stem length and fresh and dry weight of stems, leaves and roots.

Materials and methods

The experiment was conducted in 2017 at the experimental facility of the Department of Grassland and Green Areas Creation of the University of Natural Sciences and Humanities in Siedlce. Growing conditions were as follows: daytime temperature of 24 °C; night time temperature of 16 °C; light intensity of 200 μmol m^{-2} s^{-1}, obtained with high pressure sodium lamps; photoperiod of 16 hours. The plant tested in the experiment was *Trifolium pratense* L. var. Krynia, cultivated in pots. Each pot was 300 mm high, with the base diameter of 200 mm. Completely randomised and with a control unit, the experiment was carried out in three replications. The pots were filled with 5 kg of class 3 soil, in the Polish classification system, which was fine loamy sand taken from the plough layer. Additionally, it was found that soil pH (KCl) was 6.3, with $N\text{-}NO_3$ concentration of 1.4 mg kg^{-1} DM, $N\text{-}NH_4$ concentration of 60.9 mg kg^{-1} DM, and C_{org} (organic carbon) concentration of 17.1 g kg^{-1} DM. In mid-March ten seeds of *Trifolium pratense* L were planted into each pot at a depth of 1.5 cm. After germination, at the three leaf stage, the best three plants in a pot were selected, while the others were removed. Then, a fertiliser with the brand name of Stymjod was applied. Table 1 presents detailed chemical composition of the fertiliser.

There were four experimental treatments: F0 - control (plants sprayed with distilled water), F1 - plants sprayed with 1.5% solution of the fertiliser, F2 - plants sprayed with 3% solution of the fertiliser, F3 - plants sprayed with 4.5% solution of the fertiliser. Stymjod was applied twice in the form of foliar spray, at the first node stage (BBCH 23) and at the ninth node stage (BBCH 39). The following plant features were determined: shoot and leaf number, stem length (cm), fresh and dry matter of leaves, stems, and roots (g), and fresh matter of 100 leaves (g).

The results were statistically processed, using Analysis of Variance. Tukey's test was used to determine LSD 0.05 for means that were significantly different. Standard error was calculated to find out how the values spread and Statistica 6 programme was used for all data analysis.

Results and discussion

The results indicated that Stymjod application positively affected some of the features studied in the experiment (Table 2). Compared to the control (F0), even the lowest solution (F1) of the growth regulator resulted in an increase in the number of shoots by 22% and leaves by 14%. Application of

Table 1. Stymjod chemical composition.

Humus acids	Organic compounds	Iodine aqueous solution	Mineral substances (%)										
			N	P_2O_5	K_2O	MgO	SO_4	Fe	Mn	Cu	Mo	Zn	B
3.3% C kg^{-1}	56%	0.0025%	6.3	4.58	6.42	1.69	1.6	0.14	0.16	0.17	0.02	0.42	0.08

Table 2. The effect of different Stymjod solutions on shoot and leaf number, stem length and dry and fresh matter of stems, leaves and roots.

	Plant parts	Treatments			
		F0 (control)	F1 (1.5%)	F2 (3%)	F3 (4.5%)
	Shoot number	22.5^{c}	27.5^{b}	30^{ab}	32.5^{a}
	Leaf number	$1,330.5^{d}$	$1,520.5^{c}$	$1,903^{b}$	$2,504.5^{a}$
	Stem length (cm)	44.6^{a}	45.8^{a}	39.9^{b}	34.1^{c}
Fresh matter (g)	Shoots	14.2^{c}	15.4^{bc}	16.6^{b}	18.7^{a}
	Leaves	8.9^{b}	9.8^{b}	8.2^{b}	14.0^{a}
	Roots	10.4^{a}	11.3^{a}	6.6^{b}	6.7^{b}
	100 leaves	0.67^{a}	0.64^{a}	0.43^{c}	0.56^{b}
Dry matter (g)	Shoots	4.7^{b}	5.3^{a}	5.4^{a}	5.12^{ab}
	Leaves	1.9^{b}	2.2^{b}	2.3^{b}	2.9^{a}
	Roots	4.0^{a}	4.2^{a}	2.6^{c}	3.6^{b}

There was no significant difference, at $P \geq 0.05$, between figures in the same lines marked with the same superscript letter.

more concentrated solutions led to a significant growth of those features. However, F2 and F3 solution application shortened the length of stems.

Additionally, the fertiliser positively affected development of fresh and DM yield of the aboveground parts. The application of the maximum concentration (F3) of Stymjod resulted in the greatest increase in the fresh weight of stems and the fresh and dry weight of leaves. In turn, the F2 and F3 concertation limited the development of fresh and dry weight of roots. Interestingly, the smallest leaves, as indicated by the 100 leaf mass, developed when plants were sprayed with 3% solution. There have been other publications dealing with the effects of metals on *Trifolium pratense* L. biomass such as those by Whitehead (1973) and Shahbaza *et al.* (2018).

Conclusion

The result of the experiment demonstrated that Stymjod as a fertiliser for *Trifolium pratense* L. resulted in increased production of certain morphometric characteristics of the plant. The fertiliser contributed to an increase in the number of shoots and leaves. It also caused an increase in fresh and dry weight of shoots and leaves. However, it resulted in a reduction of the size of leaves and of the weight of the root system. The best results were obtained with the concentration of 4.5%.

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The legume harvest of burr medic: first experiences with a brush prototype machine

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Abstract

Medicago polymorpha L. is one of the most interesting species for forage and multiuse agricultural systems in the Mediterranean basin. Seed harvest of annual medics (*Medicago* spp.) is traditionally undertaken using an Australian vacuum harvester. This is very expensive, especially in Sardinian agricultural conditions characterised by small sized fields. For annual medics, the difficulties of harvesting are the major constraint to their increased use in Sardinia, where the only available seeds are expensively imported from Australia. To counteract these problems, a low-cost prototype machine was developed with the aim to harvest legumes of annual *Medicago* spp. from the soil in the framework of a project about biodiversity conservation and valorisation. Legumes and other materials are collected by two counter-rotating brushes and go through an initial sieve where straw and material larger than legumes are removed. Afterwards, they are conveyed to a second sieve through a vacuum duct to remove the thin materials from legumes. The potential seed yield in open field conditions was 0.6 t ha^{-1}. The harvest rate with our prototype was 14%. These preliminary tests suggest the need to improve the prototype to reduce losses of threshed legumes.

Keywords: *Medicago polymorfa* L., annual medics, seed production, harvesting methods

Introduction

Medicago polymorpha L. is one of the most interesting species for forage and multiuse agricultural systems in the Mediterranean basin (Porqueddu *et al.*, 2001; Fara *et al.*, 1997). Two new varieties, recently released, confirm the interest of this species for the Sardinian pedo-climatic conditions. Seed harvest of annual medics is traditionally made using an Australian vacuum harvester (Pau, 2008; Sulas *et al.*, 2001; Lelievre *et al.*, 1996). This system is very expensive, especially in Sardinian agricultural conditions characterised by small sized fields. For annual medics the difficulties of harvesting are the major constraint to their increased use in the Mediterranean basin, where the only available seeds are expensively imported from Australia. Due to these limitations, conditions to start a seed production chain were not favourable so far in Sardinia. Few attempts to establish a seed production at a local level have been reported in the Mediterranean basin, with one undertaken in Tunisia (Chatterton and Chatterton, 1991). To face these problems and develop a modern and efficient seed production chain in Sardinia as well as in Mediterranean multiuse agricultural systems, a low-cost prototype machine was developed with the aim to harvest legumes of *Medicago* spp. from the soil in the framework of a project about biodiversity conservation and valorisation.

Materials and methods

In order to develop the prototype, we started from a commercial machine Intermac-Procomas Mod. ST 120, developed to collect leaves and small fruits from the ground.

The prototype is equipped with two counter-rotating brushes in order to pick up the legumes from the soil (Figure 1). The collected materials are conveyed to a plain sieve to remove straw and material larger than legumes. Then, through a vacuum duct, the legumes are conducted to a rotating sieve to remove the thinnest materials.

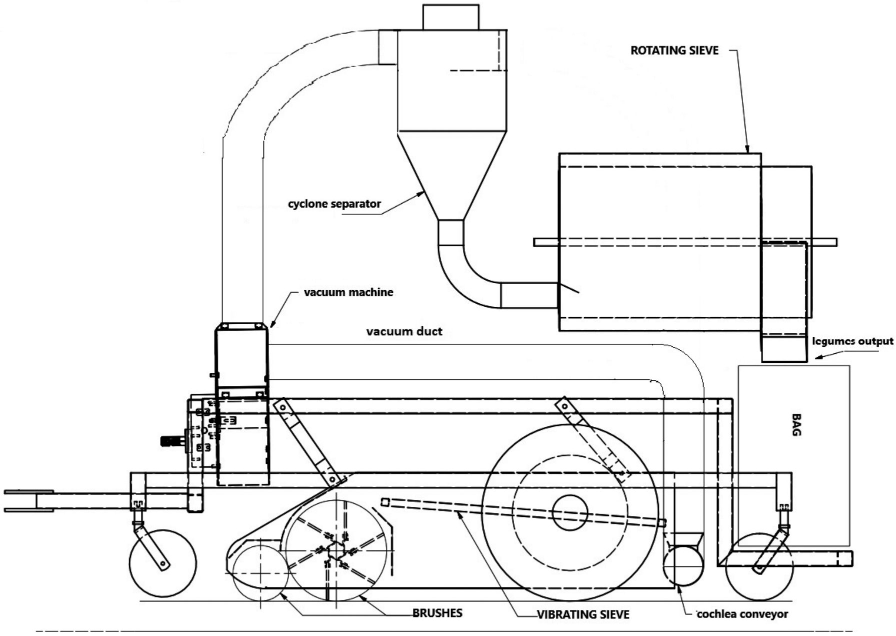

Figure 1. Scheme of the brush prototype machine.

The prototype was tested in a field of 1.2 ha, in five sampling areas of 20 m^2 each. Prior to harvesting legumes with the prototype, the potential seed yield was manually assessed by collecting the legumes in two plots of 0.1 m^2 positioned inside each sampling area for a total of ten plots. The amount of seed losses was also measured using an auxiliary bag under the rotating sieve. We also proceeded to harvest the seeds in the whole field with the Australian vacuum seed harvester Horwood Bagshow (HB). Statistical comparison between the two harvesting methods was not possible to perform: only two measurements were made because this machine requires large fields.

Results and discussion

As shown in Table 1 the collected seeds with the brush prototype represent only 14% of the potential yield, whereas the HB machine reached 33%.

Table 1. Potential yield and harvested seed with the two harvesting methods.

Plot	Potential seed yield kg ha^{-1}	Brush prototype		HB machine
		Harvested kg ha^{-1}	Seed losses kg ha^{-1}	Harvested kg ha^{-1}
1	585	30	68	219
2	690	63	42	183
3	635	194	23	
4	530	39	25	
5	615	111	49	
Mean	611	87	41	201
Std	53	60	16	

In addition to lower average yields, it is also worth noting the high variability of the collected seed and the considerable loss of seeds registered when using the brush prototype machine. Losses were due to a considerable difficulty in setting the machine especially with regards to the height of the brushes from the ground and the speed of the machine.

Furthermore, large quantities of legume seed were damaged when collected with the brush prototype. The legumes, after passing the first sieve, are conveyed to the vacuum duct and pass through the fans of the suction motor that damages them as if they had been already threshed. Hence, the collected legumes are broken and many of them have no seeds.

Conclusion

In order to be successfully used for collecting Mediterranean self-reseeding legumes, the prototype requires the following two substantial modifications: (1) substitution of the vacuum duct with a Venturi system to avoid the seeds passing through the fans of the suction motor, (2) improvements to the height adjustment of the brushes from the ground.

Acknowledgements

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Effects of Mn and Zn on root rot and biomass production in red clover (*Trifolium pratense* L.)

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Abstract

Red clover (*Trifolium pratense* L.) is the most important legume crop in Swedish forage production. The objectives of this study were to investigate the effect of manganese (Mn) and zinc (Zn) application on root rot and yield of red clover grown in monoculture or intercropped with grass in field conditions. A field experiment was established in 2014. Treatments were: (1) Mn, (2) Zn, (3) a combination of the two elements, and (4) control, in red clover cultivated in monoculture and intercropped with timothy (*Phleum pratense* L.). Yield and DM content of the first cut was measured in the first and second harvest years. Plant species were separated and weighed. Plants were collected in the middle of November each year for assessment of root rot, and the disease severity index calculated. Concentrations of Mn and Zn were analysed in roots and shoots. Application of Zn increased yield by 858 kg DM ha^{-1} of red clover while the timothy yield tended to decline. Thus, Zn application may be used to alter the composition of the forage. The two treatments including Zn showed the highest root Zn concentrations but did not affect the severity of root rot. Manganese application did not affect yield, root rot or Mn root concentration.

Keywords: *Trifolium pratense* L., root rot, manganese, zinc

Introduction

Red clover (*Trifolium pratense* L.) is the main protein crop in Swedish forage production. Common root rot caused by the soil borne pathogens *Fusarium avenaceum*, *F. Culmonorum*, *Cylindrocarpon destructans* and *Phoma medicaginis* (Rufelt 1986; Lager and Gerhardson 2002) reduce the persistence of red clover and often, the proportion of clover is greatly reduced the third year of harvest. Micronutrients are essential for plant growth and are important in plant defence mechanisms. Application of Mn and Zn reduced development of disease in a previous glass house investigation (Stoltz and Wallenhammar, 2010). The objectives of this study were to investigate the effect of Mn and Zn application in field conditions on root rot development and yield in red clover grown as a monoculture or intercropped with timothy (*Phleum pratense* L.).

Materials and methods

A field experiment with a randomized block design and four replicates was undertaken in Örebro County, (N: 59°17', E: 15°4') from 2014-2016. Plot size were 36 m^2 and the harvested area 12 m^2. Treatments were: (1) Mn, (2) Zn, (3) a combination of the two elements, and (4) an untreated control, in red clover cultivated as monoculture or intercropped with timothy (in total eight treatments). The field trial was not fertilised.

Red clover seed was treated in a NoroGard, R 150, Laboratory Seed Treater with (1) Mn (5 ml kg^{-1} seed), (2) Zn (5 ml kg^{-1} seed), or (3) a combination (3 ml Mn + 3 ml Zn kg^{-1} seed), with Norotec™ Mangan and Norotec™ Zink (Norotec, Sweden). In the field, Zn, 3 kg ha^{-1}, was applied to the treatments as $ZnSO_4^{2-}$ by spraying the soil at sowing (2014), and during the harvest years (2015-2016), plants and soil were sprayed at the beginning of stem elongation. Manganese, 1 kg Mn ha^{-1}, was applied to the treatments as $MnSO_4^{2-}$ onto plants and soil at leaf development in the seeding year and at stem elongation in the harvest years. Seeding was performed on 12 July 2014 at a rate of 8 kg ha^{-1} of red clover (cv. Ares) and 10 kg ha^{-1} of timothy (SW Switch). Yield of the first cut (17 June 2015 and 15 June 2016) was measured in the first and second harvest years. Plant species were separated and weighed. Second cuts were performed but not weighed. Ten plants per plot were collected in the middle of November each year. Roots were washed and split with a scalpel and visual assessment of root rot was performed and a disease severity index (DSI) calculated according to Rufelt (1986). Concentrations of Mn and Zn in roots and shoots during the two harvest years were analysed at Eurofins Food and Agro Testing Sweden AB, Sweden. The software JMP (©SAS Institute) was used for statistical analyses. An ANOVA was performed, followed by Tukey's HSD test if $P > 0.05$.

Results and discussion

Application of Zn increased the yield of red clover by 20% (858 kg DM ha^{-1}, $P < 0.001$) and there was a strong tendency for a corresponding reduction in the yield of timothy (Table 1). The increased yield following Zn application might be due to the repeated removal of biomass, thus red clover may become deficient in Zn. Shoot concentration of Zn in red clover was highest in the Mn + Zn treatment, but only significantly different from the Mn treatment ($P = 0.016$). The two treatments including Zn showed the highest root Zn concentrations. Manganese application did not affect shoot or root concentrations of Mn in red clover. Lower shoot concentrations of Mn and Zn in the first harvest year were probably due to dilution due to high yield compared with lower yields and higher concentrations in the second harvest year. Volunteer timothy was prevalent in the monoculture red clover treatment since the field had a history of timothy seed production. The treatment with red clover in monoculture had higher yield, lower timothy yield and a lower total yield than when red clover was intercropped with timothy (Table 1). The red clover yield and Mn shoot concentration ($P = 0.01$) was higher in the monoculture treatment than in intercropped red clover, indicating a competition for Mn by timothy.

Root rot in red clover was not affected by Mn or Zn application (Figure 1) in contrast to previous investigations (Stoltz and Wallenhammar, 2008). There was a slight tendency for reduced root rot in the Mn treatment with red clover in monoculture, however, the DSI increased similarly over time in all treatments and the level of DSI was comparable in all treatments in 2016.

Table 1. Average first cut yields, in the first and second harvest years, of red clover and timothy monocultured or intercropped and average concentrations of Mn and Zn in red clover, n = 4.

Main effects	Yield (kg DM ha^{-1})			Red clover shoot conc. (mg kg^{-1} DM)		Red clover root conc. (mg kg^{-1} DM)	
	Red clover	Timothy	Total	Mn	Zn	Mn	Zn
Treatment							
Control	4,350^{b}	3,696	8,046	23	47^{ab}	18	17^{b}
Mn	4,705^{ab}	3,356	8,060	23	47^{b}	18	18^{b}
Mn + Zn	5,011^{ab}	3,222	8,232	22	53^{a}	19	22^{a}
Zn	5,208^{a}	2,785	7,992	22	51^{ab}	16	21^{a}
	0.026	ns	ns	ns	0.016	ns	0.002
Year of harvets							
1st harvest year 2015	5,818^{a}	3,796	9,614^{a}	19^{b}	42^{b}	18	18
2nd harvest year 2016	3,818^{b}	2,733	6,551^{b}	26^{a}	57^{a}	18	20
	0.002	ns	<0.001	0.001	0.005	ns	ns
Cropping system							
Monocultureped red clover	5,329^{a}	2,150^{b}	7,480^{b}	23^{a}	50	18	20
Intercropped red clover	4,307^{b}	4,379^{a}	8,686^{a}	22^{b}	49	17	19
P-value	<0.001	<0.001	<0.001	0.01	ns	ns	ns

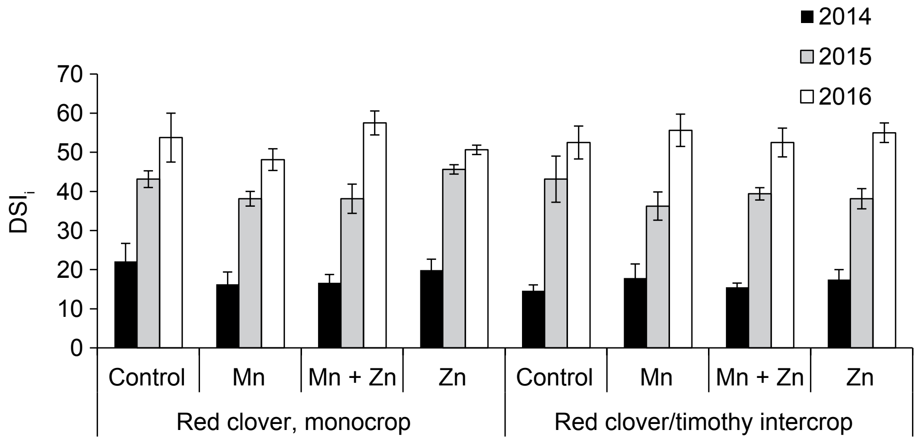

Figure 1. Average (± SE) internal disease severity index (DSI$_i$) of root rot in red cover 2014 - 2016, n = 4.

Conclusion

The results of this investigation show that Zn application may be used to increase the proportion of red clover when cultivated in mixed sward with timothy. Manganese and Zn application did not sufficiently reduce the development of root rot in red clover.

Acknowledgements

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Higher yields in formerly drought-stressed *Lolium perenne* and *Cichorium intybus* due to increased carbohydrate reserves, higher root biomass, and increased mineral soil N

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Abstract

We investigated yield resilience from drought stress in monocultures of *Lolium perenne* L. and *Cichorium intybus* L. in a field experiment in northern Switzerland. A summer drought was induced with complete rain exclusion for nine weeks. Drought effects were compared to rainfed control conditions at the end of the drought period and six weeks later after a post-drought period with adequate water supply. To explain yield responses, we measured plant-available N in the soil, water soluble carbohydrates in plant storage organs (stubbles), and root biomass of species. During the last five weeks of the drought period, *L. perenne* and *C. intybus* revealed an average change in aboveground biomass (compared to the rainfed control) of - 68% ($P < 0.001$). During the six-week post-drought period, formerly drought-stressed species were highly resilient and significantly outperformed the yield level of the rainfed control by + 62% ($P < 0.05$). This yield advantage could be explained by significantly increased concentrations of water soluble carbohydrates in storage organs (+ 64%) and higher root biomass (+ 66%) of formerly drought-stressed species, and a four-fold increase in plant-available soil N during the post-drought period. As a result, aggregated over the drought and post-drought periods, surprisingly no negative drought impact on yield was observed.

Keywords: drought experiment, yield resilience, post-drought overcompensation, water soluble carbohydrates, root biomass, drought-induced N limitation

Introduction

Lolium perenne L. and *Cichorium intybus* L. are the most important grass and forb species, respectively, in intensively managed temperate grasslands and provide forage of high quantity and quality. While *L. perenne* is known to be susceptible to drought, *C. intybus* reveals some yield resistance to water shortage, probably due to its taproots that allow for water uptake from deeper soil levels (Hoekstra *et al.*, 2015). When drought impairments on yield are severe, high resilience (recovery during a period of adequate water supply following a drought event, *sensu* Pimm (1984)) of grassland would be especially important to mitigate loss of production and income for farmers. In particular, under intensive grassland management, where high annual yields are expected with several harvests per year, one or more harvests with high yields following the drought event would mitigate total yield losses due to drought. Here, we evaluate yield resilience of *L. perenne* and *C. intybus* after a severe drought event of nine weeks. We investigated whether and to what degree the two species would recover from yield losses due to drought, and what associated factors (soil nitrogen (N) availability, species' root biomass and water soluble carbohydrates) could explain yield changes during the post-drought period.

Materials and methods

A field experiment was carried out in the north-east of Switzerland at Zürich-Reckenholz with monocultures of *Lolium perenne* L., cultivar (cv.) Alligator, and *Cichorium intybus* L., cv. Puna II, which were established in plots of 3 × 5 m. A drought treatment was established, in which an extraordinarily strong summer drought was induced, and precipitation was excluded completely for nine weeks using rainout shelters (see Hofer *et al.* (2016) for details). Unsheltered plots served as the rainfed control treatment. There were three replicate plots per species and drought treatment, and all plots received N fertiliser of 200 kg ha^{-1} $year^{-1}$ (six applications throughout the year). Aboveground biomass was harvested after four weeks of drought, five weeks later after nine weeks of drought, and after a post-drought period of six weeks. Soil moisture content was measured hourly with permanently installed sensors (EC-5 soil moisture sensor, Decagon, USA). Plant-available N in the soil was measured by the use of Plant Root Simulator (PRS)™-probes (Western Innovations, Canada) installed at 5 cm soil depth, which imitate root nitrate and ammonium sorption. Water soluble carbohydrates (WSC) in plant storage organs (stubbles) of *L. perenne* were determined using an anthrone method (see Hofer *et al.* (2017a) for details on the analysis). Root biomass of species was measured by taking soil cores (7 cm diameter, 3 per plot) at the end of the drought period from 0 to 30 cm deep. Data were analysed by analyses of variance.

Results and discussion

After four weeks of drought, decreasing soil moisture contents reached the threshold of plant-available soil water at - 1.5 Megapascal and remained clearly below this level until the end of the drought period, indicating severe water deficits to plants. At the end of the nine-week drought period, *L. perenne* and *C. intybus* were strongly affected by drought and revealed an average change in aboveground biomass (CAB, compared to the rainfed control) of - 68% (Figure 1a). During the six-week post-drought period with adequate water supply, formerly drought-stressed species were highly resilient and even significantly outperformed the yield level of the rainfed controls by + 62% (Figure 1b). As a result, aggregated over the drought and post-drought periods, the average CAB was + 1.5% (Figure 1c) and thus no negative drought impact on yield was observed.

This surprising yield advantage at the post-drought period can be explained by several factors. First, acquisition of resources not taken up during the drought event can promote resilience of yield, in particular, increased soil N availability during a post-drought period with adequate water supply (Hofer *et al.*, 2017b). Moreover, dry-rewetting events can increase soil microbial activity (Gordon *et al.*, 2008). As a result, drought events induce a post-drought pulse in N mineralisation (Borken and Matzner, 2009) and a short-term increase in soil fertility (Bloor and Bardgett, 2012). Indeed, in our experiment, we observed more than four-fold higher plant-available N in the soil at former drought-stressed stands compared to control conditions ($P < 0.001$, no figure shown). Second, under drought the grass *L. perenne* had significantly increased concentrations of WSC in the stubbles (+ 64%, Figure 2). Plants under drought can accumulate carbohydrates due to less demand for growth (Burri *et al.*, 2014), and excess carbohydrate stocks might promote fast growth after the drought event. Third, under drought both *L. perenne and C.*

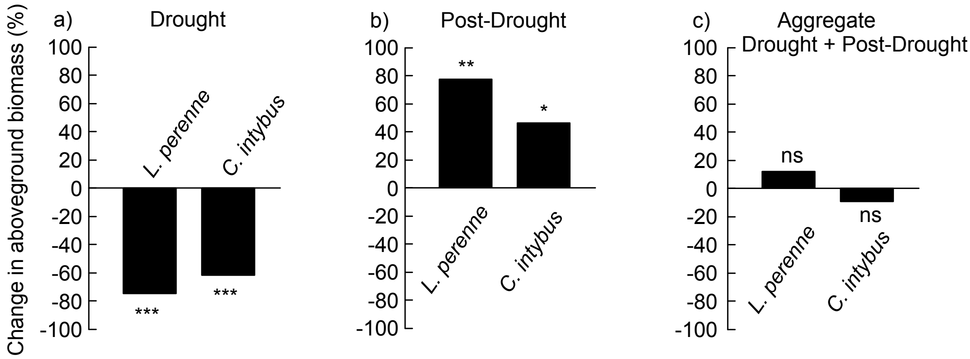

Figure 1. Change in aboveground biomass (compared to the rainfed control) of *L. perenne* and *C. intybus* (a) after five weeks of growth at the end of a nine-week drought period, (b) after a six-week post-drought period with adequate water supply, and (c) based on aggregated yields over the two harvests during the drought period and the harvest at the end of the post-drought period. *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$, ns: $P > 0.1$

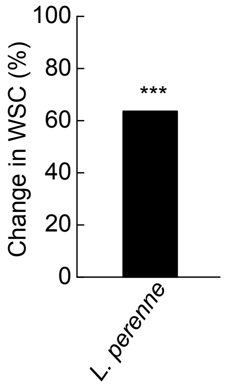

Figure 2. Change in water soluble carbohydrates (WSC) in stubbles of *L. perenne* after a nine-week drought period compared to the rainfed control. *** $P < 0.001$

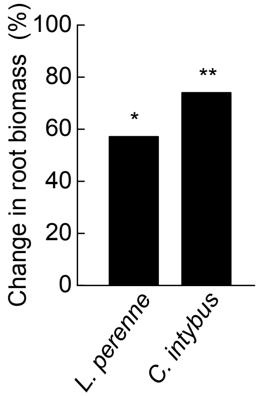

Figure 3. Change in root biomass of *L. perenne* and *C. intybus* after a nine-week drought period compared to the rainfed control. ** $P < 0.01$, * $P < 0.05$.

intybus revealed an increase in root biomass of + 66% (Figure 3). Drought-stressed species might increase root biomass to improve resource acquisition under stressed conditions. Such higher root mass may allow for higher resource uptake during the post-drought period and improve resilience. Taken together, all three factors, increased soil N availability, higher WSC and root biomass, can explain the yield advantage after the severe drought event.

Conclusion

L. perenne and *C. intybus* were highly resilient to severe drought: during post-drought growth, formerly drought-stressed plants did not only reach yields of unstressed plants but clearly exceeded these levels. A combination of increased carbohydrate reserves and root biomass at the end of the drought period, along with increased plant-available soil N during the post-drought period, can explain this surprising resilience. As a result, aggregated over drought and post-drought periods, only marginal drought effects on yields were observed.

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Xerothermic grassland as a source of forage for small ruminants

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Abstract

High nature value (HNV) areas may be a potential source of forage for livestock. Xerothermic grassland (thermophilic communities of marginal land on calcareous soils) in Polish conditions is an example of a possible compromise between livestock farming and active nature conservation because using them as a forage source supports their effective protection against degradation. Among HNV areas, Natura 2000 sites are a significant part of permanent grassland representing a variety of habitats and communities. This study was aimed at determining the fodder potential of grassland communities of the type of xerothermic grasslands on which various forms of protection were implemented. Field and laboratory research was carried out in the years 2016 - 2017. Representative points were determined on the paddocks from which samples were taken for testing in three replications. The productivity and rate of use of sward by animals were studied. The basic feed quality parameters were determined, i.e. energy, fibre, protein and sugar contents, as well as digestibility of dry matter (DM). The fodder quality of xerothermic sward in areas where active protection is kept is sufficient for extensive grazing of sheep and goats. The variable fibre content of plants may be a limiting factor in the use of forage by animals. A high diversity of botanical composition and DM yield requires further research to precisely determine their utility value.

Keywords: xerothermic grassland, rendzina soil, yield, fodder quality

Introduction

High Nature Value (HNV) habitats are threatened throughout Europe. The greatest threat to permanent grasslands is the cessation of use and alteration of water and trophic relationships in habitats (Sienkiewicz-Paderewska and Stypiński, 2009). They decline due to the abandonment of extensive farming, traditional farming methods and the intensification of agriculture (Zarzycki and Szewczyk, 2013). Xerothermic grass communities, the occurrence of which is determined by specific conditions (calcareous soils, strong sunlight, high temperature of air and soil) require effective and sustainable protection, not only by cutting down trees and bushes that shade the lower parts of the sward, which limits the growth and development of plants, but also by exposing the surface to well-timed and extensive animal grazing (Michalik and Zarzycki, 1995, Dzwonko and Loster, 1998). There are currently 159 Natura 2000 sites in Poland where xerothermic turf is protected. In Małopolskie Voivodeship, there are 30 such areas, of which 18 are located in the Miechów district. The aim of the study was to evaluate the usefulness of xerothermic grasslands as a source of feed for small ruminants.

Materials and methods

The study covered six areas included in the Natura 2000 network. In the past, they were used as pastures but following abandonment in the 1990's they were systematically degraded. The six areas were: PLH120063 Chodów-Falniów (1) - 4.04 ha, PLH120054 Kalina Mała (2) – 1.60 ha, PLH120062 Kaczmarowe Doły (3) – 2.85 ha, PLH120074 Sławice Duchowne (4) – 1.03 ha, PLH120075 Uniejów Parcele (5) – 0.60 ha, PLH120076 Widnica (6) – 1.05 ha.

These areas are located on shallow rendzina, calcareous type of soils. Prior to the start of the research, they required partial restoration so active protection was carried out at the beginning of 2015 and consisted of clearing of trees and bushes and mowing of the surface. Grazing by sheep (indigenous local breed

Olkuska) has been conducted since May 2015 in three rotations per year. For each area, the stocking density and the number of grazing days were calculated so that the average stocking rate was 0.5 livestock unit (LU) ha^{-1} $year^{-1}$. No fertiliser was applied to avoid the risk of excessive eutrophication of habitats.

The studies and evaluations were conducted in 2016 - 2017. In subsequent rotations, the DM yield before and after grazing were measured (0.5 m^{-2} cut at a height of 3 cm). Before grazing, the proportions of grasses, legumes and other plants in the yield were evaluated. Samples were taken from the designated points representative for the area (transect method, three replicates from each sampling point) and analysed for dry matter (DM) content, crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) content. The DM content was determined after drying at 105 °C, and the Kjeldahl method was used to determine nitrogen (N) (AOAC, 1990). Crude protein content was calculated as N × 6.25. Neutral detergent fibre, ADF and ADL contents were determined according to the methods of Van Soest *et al*. (1991) using the Foss Tecator Fibertec System M6. Data were statistically analysed for significance by ANOVA and Tukey's test.

Results and discussion

The study areas differed significantly in terms of species composition. A reference to the results can be found in other works of the authors (Musiał *et al*., 2017). The dominant plant fraction reaching 86% of DM yield was grass (Table 1).

The only exception was PLH 120074, dominated by herbs and weeds (81%). Share of legumes ranged from 4 to 16% of DM yield. The potential DM yield of the examined paddocks was similar considering that the rate of sward use varied. The lowest grazeable DM yield of forage (0.92 t ha^{-1}) was found on paddocks with the highest proportions of herbs and weeds in the sward. Differences in DM yield between rotations and years were also observed. With high variability of species composition, heterogeneous evaluation of the fibre fraction was expected (Van Soest *et al*., 1991). Analyses showed similar ADL content and significant differences in NDF and ADF fibre content. The study confirms findings from other sources (Jančík *et al*., 2008; Goliński *et al*., 2017) who found that, as well as the positive effect on grassland biodiversity, agricultural utilisation may also be an economically justified method of maintenance for protected areas.

Table 1. Characteristic of the pasture sward and forage harvested from six study areas. Data are derived from three rotations (spring, early and late summer) in two grazing years (2016 - 2017).[1]

	Chodów-Falniów (1)	Kalina Mała (2)	Kaczmarowe Doły (3)	Sławice Duchowne (4)	Uniejów Parcele (5)	Widnica (6)
Proportion of grasses (%)	71	64	79	14	86	85
Proportion of legumes (%)	5	14	16	5	4	7
Proportion of others (%)	24	22	5	81	10	8
Potential yield (t DM ha^{-1})	7.7ns*	7.6ns	9.6ns	5.4ns	5.6ns	8.8ns
Grazeable yield (t DM ha^{-1})	4.24^{b}	4.79^{b}	4.03^{b}	0.92^{a}	1.40^{a}	4.05^{b}
CP content (%)	6.9^{a}**	9.0^{b}	6.8^{a}	8.4^{b}	10.0^{c}	6.2^{a}
CP yield (kg ha^{-1})	292^{c}	431^{d}	274^{c}	77^{a}	140^{b}	251^{c}
NDF content (%)	49.8^{b}	50.2^{b}	46.9^{a}	54.2^{c}	52.7^{c}	49.6^{b}
ADF content (%)	29.5^{ab}	26.9^{a}	28.2^{a}	32.4^{b}	31.3^{b}	28.5^{a}
ADL content (%)	3.11ns	3.05ns	3.66ns	3.35ns	3.25ns	3.73ns

[1] *: no significant difference; **: the same letters denote homogeneous groups.

Conclusion

The requirement to protect valuable natural habitats remains a potential source of forage for animal husbandry. Sheep grazing, particularly native breeds, is a good option to manage such grasslands despite the heterogeneity of forage quality. Variability of forage resources during the grazing season requires monitoring of forage supply and a precise determination of the stocking density.

Acknowledgements

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The nutritive value of alaska brome and tall fescue forage using different growing technologies

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Abstract

New varieties of alaska brome (*Bromus sitchensis* Trin.) and tall fescue (*Festuca arundinacea* Schreb.) have gained attention of producers because of their winter-hardiness, high yielding ability and fast growth. Alaska brome cv. Hakari and tall fescue cv. Barelite were grown in field tests during the years 2016 and 2017 in a mixture with red clover (*Trifolium pratense* L.) cv. Varte. The plots were cut three times during the summer. The average DM yield over two years in the organic monocultures was 5.7 t ha^{-1} for tall fescue and 5.9 t ha^{-1} for alaska brome. In the mixture with red clover the DM yield was accordingly 13.8 and 14.5 t ha^{-1}. The forage with the highest nutritive value was obtained growing grasses in the organic mixture with red clover (digestible DM 635 - 673 g kg^{-1} DM, crude protein (CP) 122 - 188 g kg^{-1} DM, metabolisable energy 9.8 - 10.4 MJ kg^{-1} DM), however, the tall fescue showed better results. The nitrogen fertiliser used in the conventional farming increased the DM yield and the CP content of the forage.

Keywords: Alaska brome, tall fescue, grass mixtures, forage yield, forage nutritive value

Introduction

An optimal combination of suitable grass and legume companion species is needed to obtain high nitrogen (N)-use efficiency, high herbage yield and high contents of nutritive compounds in grass-legume mixtures (Elgersma and Søegaard, 2015). Red clover (*Trifolium pratense* L.) is an increasingly important forage legume in such systems as it can produce large DM yields of high quality forage (Frame *et al*., 1997). The nutritive value is highest when the first cut is taken at budding or at the beginning of flowering. In order to balance the need for N fertiliser with biological N fixation, it is favourable to grow red clover in a mixture with grasses. When choosing legumes for grass-clover mixtures, the rate of phenological development of the species, persistency and nutritive value should be considered. Earlier results have shown that growing red clover in mixtures with grasses improves the nutritive value and ensiling properties of the crop (Tamm, 2017). The aim of this experiment was to study the effects of companion grasses and red clover in mixtures on herbage yield and forage quality.

Materials and methods

The experimental field was established in 2015 in Saku, Estonia (local latitude 57° 25'). The study includes data from two years (2016 - 2017). The trial plots were established on a typical soddy-calcareous soil where the agrochemical indicators were as follows: pH_{KCl} 7.1 (ISO 10390); soil carbon content C_{org} 5.0% (Tyurin method) and the concentration of lactate soluble phosphorus (P) and potassium (K) was 247 and 228 mg kg^{-1} (Mehlich III method), respectively. The sowing rate of alaska brome (*Bromus sitchensis* Trin.) cv. Hakari *(Bs)* was 28 kg ha^{-1}, tall fescue (*Festuca arundinacea* Schreb.) cv. Barelite *(Fa)* was 30 kg ha^{-1} and red clover cv. Varte *(Tp)* was 10 kg ha^{-1}. The trials were established in a split-plot design in three replicates and the size of the harvested plot was 14 m^2. Three different treatments were compared across both grass types in the experiment: two organic farming treatments (whereby alaska brome and tall fescue were sown as monocultures with and without red clover and received 0 kg N ha^{-1}) and a conventional farming treatment where alaska brome and tall fescue were sown as monocultures and received 200 kg N ha^{-1} (N200) in three applications (80 - 60 - 60, respectively). The crop was cut by a scythe and then weighed and samples were taken for analyses. A three-cut system was used during harvest. The first cut was taken between 3 - 15 June. Effective temperatures over 5 °C for the first cut were 288 °C in 2016 and 244 °C in 2017. When the adapted red clover was in bud stage, the second cut was taken in late July and the third cut in early September. The following data were collected in this experiment: DM yield, crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), metabolisable energy (ME) contents and digestible DM (DDM). The data was analysed with three-way ANOVA with mixture, N-fertilisation and year as fixed factors. For the statistical analysis the Tukey-Kramer Honest Significant Difference (HSD) test was used via the software *JMP 5.0.1.2* (SAS, 2002).

Results and discussion

The highest DM yield of the two experiment years was obtained from alaska brome supplied with 200 kg N ha^{-1} and the alaska brome-red clover mixture, the average yields varied from 14.5 to 15.6 t ha^{-1}. The grass-red clover-mixtures returned high DM yields in all experiment years. Yields varied from 12.1 to 15.5 t ha^{-1} (Table 1).

Over the two years there was a significant difference in the DM yields of the three treatments (between N0 and the N200 and red clover mixture treatments). The changes in quality in the first and second cuts were greater compared to the third cut. Lower CP concentrations (86 - 108 g kg^{-1} DM) were found in treatments without N fertiliser in the first and second cuts of grasses. Crude protein concentration was greatest in the N200 treatments (119 - 153 g kg^{-1} DM) (Table 2). The N fertiliser used in the conventional farming increased the forage yield and CP concentration. Red clover increased the CP concentration of the mixture. In the mixtures tall fescue was less competitive than alaska brome, thus the CP concentration of the alaska brome-red clover mixtures was lower than in the tall fescue-red clover mixtures. Neutral detergent fibre is an indicator of the nutritive value of the forages and helps to account for the feed intake potential of forages. In all cuts the NDF of the red clover mixture treatments was lower than the NDF of the grass treatments because the concentration of the cell walls is higher in the grasses than in the red clover. The grass-red clover mixtures all had high DDM (635 - 673 g kg^{-1} DM). Metabolisable energy value was greater in tall fescue mixtures compared to alaska brome one due to higher fibre concentration of alaska brome compared to tall fescue.

Table 1. The DM yield (t ha^{-1}) of alaska brome and tall fescue grass mixtures receiving either 0 (N0) or 200 (N200) kg N ha^{-1} or sown in a mixture with red clover (*Tp* mixture) in 2016 - 2017.[1]

Species	Treatment	2016	2017	Average
Alaska brome *(Bs)*	N0	7.4^{c}	4.4^{d}	5.9^{b}
	Tp mixture	15.0^{b}	14.0^{ab}	14.5^{a}
	N200	16.4^{a}	14.8^{a}	15.6^{a}
Tall fescue *(Fa)*	N0	6.4^{c}	5.0^{d}	5.7^{b}
	Tp mixtures	15.5^{ab}	12.1^{c}	13.8^{a}
	N200	14.4^{b}	13.1^{b}	13.8^{a}
$p > F$		< 0.001	< 0.001	< 0.001

[1] Different letters behind the mean values indicate significant differences at $P < 0.05$ (Tukey-Kramer HSD test).

Table 2. The nutritive value of the alaska brome *(Bs)*, tall fescue *(Fa)* and grass-red clover *(Tp)* mixtures in 2016 - 2017.[1]

	Species	Treatment	CP	NDF	ME	DDM
			g kg^{-1}	g kg^{-1}	MJ kg^{-1}	g kg^{-1}
First cut	Alaska brome	N0	108^{ab}	565^{a}	9.9^{a}	633^{b}
		(Tp)	122^{ab}	515^{ab}	9.8^{a}	635^{b}
		N200	153^{a}	582^{a}	9.7^{a}	622^{b}
	Tall fescue	N0	108^{b}	574^{a}	9.9^{a}	632^{b}
		(Tp)	137^{ab}	452^{b}	10.2^{a}	663^{a}
		N200	133^{ab}	585^{a}	9.8^{a}	621^{b}
	$p > F$		0.04	0.006	ns	0.05
Second cut	Alaska brome	N0	86^{b}	611^{a}	9.7^{b}	620^{b}
		(Tp)	184^{a}	439^{b}	10.3^{a}	663^{a}
		N200	119^{ab}	617^{a}	9.7^{b}	622^{b}
	Tall fescue	N0	108^{ab}	512^{ab}	10.5^{a}	671^{a}
		(Tp)	188^{a}	417^{b}	10.4^{a}	673^{a}
		N200	149^{ab}	518^{ab}	10.5^{a}	671^{a}
	$p > F$		0.011	0.002	0.023	0.022
Third cut	Alaska brome	N0	130^{b}	509^{ab}	10.3^{a}	657^{ab}
		(Tp)	231^{a}	413^{ab}	10.6^{a}	680^{ab}
		N200	188^{ab}	597^{a}	9.8^{a}	626^{b}
	Tall fescue	N0	136^{b}	462^{ab}	10.4^{a}	663^{ab}
		(Tp)	226^{a}	353^{b}	10.9^{a}	704^{a}
		N200	160^{b}	509^{ab}	10.4^{a}	661^{ab}
	$p > F$		0.002	0.05	ns	0.05

[1] CP = Cruäde protein; DDM = digestible DM; ME = metabolisable energy; NDF = neutral detergent fibre.

Conclusion

The highest DM yield of the two experimental years was obtained from alaska brome supplied with N fertiliser and alaska brome-red clover mixture. In the mixtures, tall fescue was less competitive than alaska brome, thus the CP content of the alaska brome-red clover mixtures was lower than the tall fescue-red clover mixture. The higher yielding ability and similar higher ME value was obtained in tall fescue mixtures.

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Variability of plant species composition and main functional groups in the Rengen Grassland Experiment

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Abstract

To examine the variability of plant species composition and main functional groups, vegetation data collected in the Rengen Grassland Experiment in the Eifel Mountains (Germany) in the years 2005 - 2014 were evaluated. The experiment was established in 1941. It is a complete randomised block design with five treatments and five replicates. The treatments are: B. Calcium (Ca), C. Ca and nitrogen (N), D. Ca, N, phosphorus (P), E. Ca, N, P, potassium chloride (KCl), F. Ca, N, P, potassium sulfate (K_2SO_4) and one control, zero fertiliser treatment (A.). The swards in all treatments were cut twice a year in late June or early July and in mid-October. Plant ground cover was estimated by visual observation in percentage in each plot in late June. Long-term fertilisation caused significant changes in plant communities. The cover of all main functional groups, except legumes, was relatively stable in the treatments over the ten years of the study. In the case of individual plant species, the highest variability of cover were observed in species such as *Briza media* L. (treatments B and C), *Festuca rubra* agg. L. (treatments C and A), *Rhinanthus minor* L. (treatments B and A), *Succisa pratensis* L. (treatments B and A), *Carex panicea* L. (treatment C) and *Trifolium pratense* L. (treatments B, E, F and A). Generally, the cover (%) variability of the main functional groups were low and spatiotemporal changes in the sward were mainly caused by the cover (%) variability of individual plant species.

Keywords: plant cover, nutrients, long-term changes, Eifel Mountains

Introduction

Fertilisation of grasslands is usually one of the main factors increasing biomass productivity. To examine the effect of different nutrients on biomass production in different soil and climatic conditions, a lot of fertiliser experiments were established world-wide. Rengen Grassland Experiment (RGE) is extraordinary because it is one of the oldest continuously managed, fully replicated fertilised experiments in the world (Schellberg *et al.*, 1999). The first detailed evaluation of plant species composition in the different treatments in RGE was examined in 2005 (Hejcman *et al.*, 2007). To quantify species stability or variability under different fertiliser treatments, the ten year vegetation data were evaluated from the years 2005 - 2014. The research question was: What is the effect of treatment on the variability of plant species composition and main functional groups in a ten year period?

Materials and methods

An experimental site was established in 1941 in extensively grazed heathland in the Eifel mountains at the Rengen Grassland Research Station of the University of Bonn, Germany (50°13' N, 6°51' E). The experiment site is 475 m above sea level with mean annual precipitation of 811 mm and mean annual temperature of 6.9 °C (Rengen meteorological station). The soil is classified as a Stagnic Cambisol. From 1941 to 1962 the experimental area was mown once per year (with period of no management from 1945 to 1950).The experimental area has been mown twice per year (in late June/early July and October) since 1962. The experiment is arranged in five randomised blocks with five fertilised treatments and one control. The size of an individual plot is 3 × 5 m. Applied nutrients, in kg ha^{-1} $year^{-1}$, are: A. control (no fertiliser); B. Calcium (Ca; Ca = 715, Mg = 67); C. Ca and nitrogen (N; Ca = 752, N = 100, Mg = 67); D. Ca, N, and phosphorous (P; Ca = 936, N = 100, P = 35, Mg = 75); E. Ca, N, P and potassium chloride (KCl; Ca = 936, N = 100, P = 35, K = 133, Mg = 90); F. Ca, N, P and potassium sulphate (K_2SO_4; Ca = 936, N = 100, P = 35, K = 133, Mg = 75). The percentage ground cover of all vascular plant species was visually estimated in the centre area (1.8 × 3.2 m) of each plot in June of each year (Hejcman *et al*., 2007). The following main functional groups were recognised: legumes (plants from family *Fabaceae*), short graminoids (mean height below 0.5 m), tall grasses (mean height ≥ 0.5 m), and similarly short and tall forbs. Repeated ANOVA and RDA analyses were used to analyse vegetation data.

Results and discussion

According to RDA analysis, the explained variability on the first axis ranged between 53.21 to 62.46% and the explained variability of all axes ranged between 66.73 to 75.77% (Table 1). This strong explanatory power of the fertiliser treatments was relatively stable during the ten years of observation and it is usually found in heavily fertilised oligotrofic grasslands (Hejcman *et al*., 2007).

The cover of short graminoids was relatively stable during the experiment in all treatments with the exception of treatments B and C (Figure 1a). In the control and less fertilised treatments (A, B, C) the variability in the cover (%) of tall graminoids (Figure 1b) and in the cover (%) of tall forbs (Figure 1d) was lower, than in more fertilised ones (D, E, F). Treatments B and C had higher proportions of short forbs and they had the lowest cover (%) variability of all functional groups in all treatments (Figure 1c). Tall grasses *Arrhenatherum elatius* L., *Alopecurus pratensis* L. and *Trisetum flavescens* L. and tall forbs such as *Galium mollugo* L. had higher cover (%) variability in the fertilised (D, E, F) treatments than in control and less fertilised treatments (B, C). On the other hand, short grass *Briza media* L., tall grass *Festuca rubra* agg. L. and short forbs such as *Leucanthemum vulgare* L., *Plantago lanceolata* L. and *Rhinanthus minor* L. had higher cover (%) in A, B, C treatments, than in fertilised (D, E, F) ones. *Trifolium pratense* L. had the highest cover (%) variability in A, B, E, F treatments, and lower cover (%) variability in C and D treatments. However, the highest cover (%) variability during the ten years of the study was revealed for legumes, which are known to have large inter-seasonal variability (Herben *et al*., 2017).

Table 1. Results of RDA analysis of plant species composition in each year of the experiment - % explanatory variability explained by one (all) ordination axis (measure of explanatory power of the explanatory variables); *F*-ratio: *F* statistics for the test of particular analysis; *P*-value (for all experimental years $P < 0.001$); Covariables (blocks); Explanatory variables (A, B, C, D, E, F).

Year	% expl. var. 1st axis (all axes)	*F*-ratio 1st axis (all axes)
2005	53.21 (66.73)	26.2 (9.2)
2006	54.40 (68.00)	27.4 (9.8)
2007	60.19 (74.5)	34.8 (13.4)
2008	59.39 (72.14)	33.6 (11.9)
2009	59.77 (74.95)	34.2 (13.8)
2010	62.46 (75.77)	38.3 (14.4)
2011	61.16 (73.49)	36.2 (12.8)
2012	60.84 (73.21)	35.7 (12.6)
2013	56.21 (71.20)	29.5 (11.4)
2014	57.87 (75.39)	31.6 (14.1)

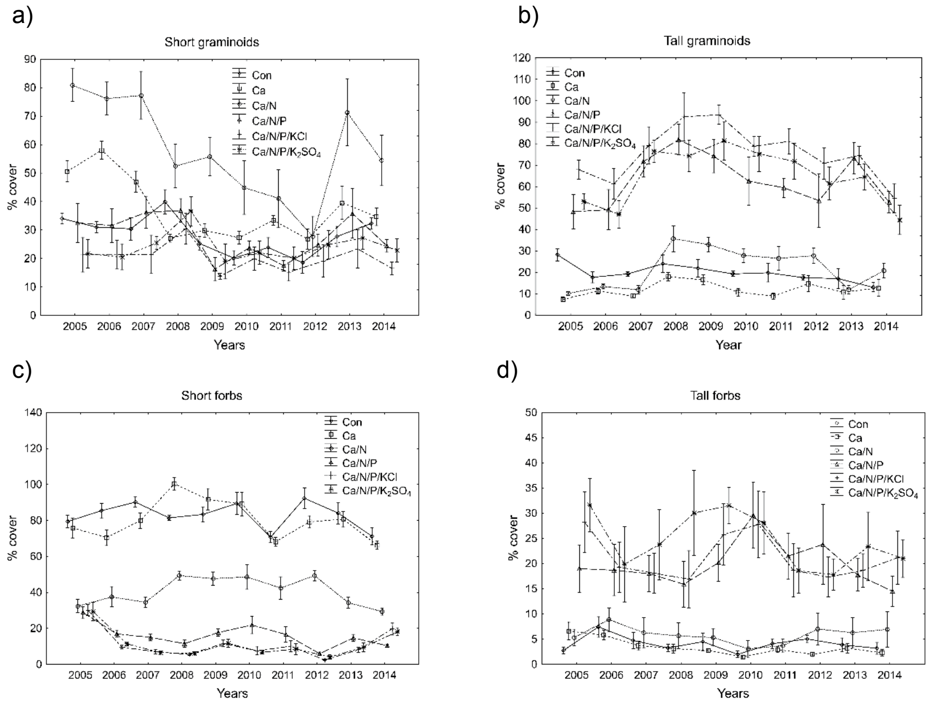

Figure 1. Percentage cover of main functional groups in six investigated treatments.

Conclusion

The strong explanatory power of fertiliser treatments (53 - 63%) was relatively stable during the ten years of the observation. Generally, the cover (%) variability of the main functional groups (with the exception of legumes) such as short forbs, tall forbs and tall grasses were relatively low in all treatments and spatio-temporal changes in the sward were mainly caused by the cover (%) variability of individual plant species.

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Optimisation of N fertilisation in Italian ryegrass (*Lolium multiflorum* L.) seed production

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Abstract

For most crops, N fertiliser advice is available and increasingly used among farmers in Belgium. The N fertilisation of Italian ryegrass (*Lolium multiflorum* L.) for seed production is based on farmer's experience as little field trial information is available to define a fertiliser recommendation. Eight field trials (2008 - 2015) were conducted in sandy loam soil to determine optimal N fertilisation. Logistic modelling revealed that maximum seed yield can be obtained when 141 kg N ha^{-1} is available (N mineralisation + fertilisation). This corresponds to an average fertilisation of 92 kg N ha^{-1} after the forage cut, either in a single application or as a split application. In a split application, 60 kg N ha^{-1} should be fertilised after the forage cut and additional N should be supplied when the NNI (nitrogen nutrition index) at the two to three node stage (BBCH 32 - 33) is below the critical point (0.83).

Keywords: Italian ryegrass, seed yield, optimal N fertilisation, splitting N fertilisation

Introduction

In Belgium, approximately 2,000 ha are currently used for seed production of Italian ryegrass (*Lolium multiflorum* L.) (IR). The IR seed crops are usually managed as combined forage-seed production systems where a forage cut is taken in spring and seeds are harvested in summer. Currently, most IR grass seed growers routinely apply the same amount of granular N fertiliser and rely on past experience. Given the current problems with nitrate leaching (D'Haene *et al.*, 2014), farmers are urged to rationalise N fertilisation in all crops. However, general N recommendations for seed yield in IR are not accurate enough and may lead to either insufficient or excessive N rates. The objectives of the present study were (1) to determine the optimal N fertilisation rate and (2) to determine whether split application of the N fertilisation is beneficial.

Materials and methods

Eight similar seed production trials (2008 - 2015) were conducted on light sandy loam soil types (50°58'N, 03°44'E, 11 m above sea level, average annual temperature and rainfall of 9.9°C and 780 mm). In each trial, two IR cultivars were evaluated: cv. Melclips (2x) and cv. Melquatro (4x). A preceding forage cut was taken just before heading (BBCH 49 - 51), after which experimental N treatments were applied (calcium nitrate 15.5%N). Five single-application N strategies were tested: 0, 60, 90, 120 and 150 kg N ha^{-1}. A split-application strategy was also tested from 2011 to 2015 (five years): 60 kg N ha^{-1} directly after the forage cut and 30 kg N ha^{-1} at the 2 to 3 node stage (BBCH 32 - 33). A split-plot design was used with two cultivars as whole plots and N treatments as subplots (four replicates). All trials were first harvest year seed crops sown during the previous autumn with row width of 15 cm and 800 germinal seeds per m^2. The seed yield is expressed in kg ha^{-1} at 12% seed moisture content.

For all modelling analyses, seed yield was expressed as relative seed yield, calculated for each cultivar relative to the maximum seed yield with single-application strategies in that trial year. The total available N was calculated as the total fertilised N after the forage cut plus the additional N supplied from mineralisation. The net amount of N mineralisation from soil organic matter and crop residues was estimated through the aboveground N uptake in unfertilised plots at BBCH 61. The following logistic regression model proposed by D'Haene *et al.* (2014) was used: seed yield = $a/(1+e^{b-cN})$ (% of maximum attainable seed yield), where a = the maximum attainable seed yield (%), b = intercept parameter for seed yield at zero available N, and c = response coefficient for seed yield and N rate. Model fitting was done using the Levenberg- Marquardt algorithm. The critical N rate was defined as the N rate where 95% of the maximum seed yield is achieved.

Results and discussion

Seed yields increased between 0, 60, and 90 kg N ha^{-1} in the single N applications. No differences in seed yield were found between 90, 120 and 150 kg N ha^{-1} (Table 1). The logistic model indicated a good relationship between seed yield and the total available N after the forage cut (Figure 1). Since the logistic model pinpointed that 141 kg N ha^{-1} should be available after the forage cut to attain maximum seed yield (Figure 1) and 49 kg N ha^{-1} was supplied on average (all years and cultivars) by the soil N mineralisation, we recommend 92 kg N ha^{-1} for a single N fertiliser application after the forage cut. We observed no significant differences in single or split N fertilisation of 90 kg N ha^{-1} (Table 1). To intercept annual and spatial differences in soil N mineralisation, the fertiliser application can be split, where the first application is standard (60 kg N ha^{-1}) and the second application depends on the actual situation.

When a split-application N strategy is used, the farmer needs a tool to determine whether a 2nd N application is needed and how much N should be applied. This tool is an estimate of the crop's N status. We tested two tools: NNI (nitrogen nutrition index) and NDVI (normalised difference vegetation index). The NNI is the ratio between the actual and the critical N content at a particular grass biomass and describes the intensity of the N deficiency. The NNI was determined at growth stages BBCH 32 - 33 (2 - 3 node stage), 51 (beginning of heading) and 61 (full ear emergence), using the N content of the above ground plant material and the critical N dilution curve as described by Lemaire and Salette (1984) for forage grasses. The NNI values at all growth stages predicted seed yield well and a critical NNI can be determined at all tested growth stages. Therefore, we believe that the optimal growth stage for tissue testing is BBCH 32 - 33, as applications at this stage can still remediate N deficient crops while later applications are often ineffectual. When the NNI at BBCH 32 - 33 is below 0.83, additional N should be supplied. The determination of the N content is costly and time-consuming for farmers. In contrast, using an optical sensor to determine the NDVI is comparably fast and simple. Our experiments revealed that NDVI, determined with a 'Greenseeker' scanner was correlated with NNI values, but was also heavily influenced by trial year. Therefore, with the current data it is impossible to establish NDVI thresholds to decide on remedial N fertilisation.

Table 1. Left: average seed yield of Melclips (2x) and Melquatro (4x) at single N applications on average (2008 - 2015) and on average over cultivars (2008 - 2015). Right: average seed yield for two split-application strategies compared to the corresponding single-application strategies in the same trial years (2011 - 2015) and as an average for the two cultivars.[1]

Cultivar	Seed yield (kg ha^{-1}) after N strategy (kg N ha^{-1})					N strategy	Seed yield
	0	60	90	120	150	(kg ha^{-1})	(kg ha^{-1})
Melclips (2x)	828 ± 52	1,370 ± 41	1,470 ± 42	1,480 ± 44	1,510 ± 39	60	$1,500^{A}$ ± 48
Melquatro (4x)	826 ± 41	1,730 ± 40	1,930 ± 47	1,930 ± 46	1,930 ± 49	60 + 30	$1,610^{AB}$ ± 48
Average	830^{a} ± 30	$1,550^{b}$ ± 40	$1,700^{c}$ ± 40	$1,710^{c}$ ± 40	$1,720^{c}$ ± 40	90	$1,640^{B}$ ± 58

[1] a, b, c indicate significant differences between seed yields of the average cultivar at five single-application N strategies (ANOVA, $P < 0.05$). A, B indicate significant differences between N strategies 60, 60 + 30 and 90 at three growth stages in 2011 - 2015 (ANOVA, $P < 0.05$).

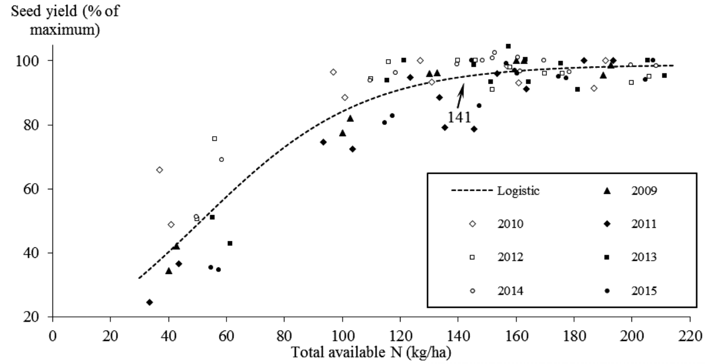

Figure 1. Maximum attainable seed yield (%) in function of the total available N after the forage cut, with a logistic (r = 0.93) model. Split-applications were excluded.

Conclusion

Logistic models indicated that IR seed crops need 141 kg N ha^{-1} (corresponding to an average fertilisation of 92 kg N ha^{-1}) after the forage cut to attain maximum seed yield. Depending on the soil N mineralisation, farmers should be advised to fertilise 92 kg N ha^{-1} after the forage cut, either in a single application or as a split application. In a split application, 60 kg N ha^{-1} should be fertilised after the forage cut and additional N should be supplied when the NNI at BBCH 32 - 33 is below the critical point (0.83).

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Medicago polymorpha L.: a natural nitrogen resource for forage eco-systems improvement

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Abstract

Unpublished data that underline the efficiency of burr medic (*Medicago polymorpha* L.) in mixture with grasses suggest its potential to enhance forage production. Due to its beneficial effect in mixtures, this species can be defined as a 'gregarious plant', leading to improvement in forage yield and quality. In fact, it is a natural and sustainable protein resource of the Mediterranean basin, largely employed in ley farming systems of Australia. In the forage systems, grass/legume mixtures can be a valid alternative to their rotations, overall for immediate nitrogen availability, thereby limiting its loss to the atmosphere. In Sardinia, recent experiments have shown that *Medicago polymorpha* L. cv. Pratosardo had a higher protein content than the annual clovers usually grown in the Mediterranean environments, such as *Trifolium alexandrinum* L., *Trifolium squarrosum* L. or *Trifolium incarnatum* L. Pure crops of ryegrass and oats had a significantly lower protein content even when N-fertilised. The mixtures with burr medic showed a better performance, both for yield and forage quality.

Keywords: *Medicago polymorpha* L., intercropping, rotation, sustainability, yield, protein

Introduction

Burr medic, due to its adaptability, is a typical floristic component of Mediterranean pastures in different pedo-climatic conditions.

Medicago polymorpha L. (*M.p.*) cv. Pratosardo was tested in various Sardinian environments, in pure stands and in mixtures. The validity of grass/legume intercropping compared to pure crop is still debated (Willey, 1979; Mariotti *et al*., 2006). Legumes are a natural source of vegetable proteins and play a key role in the sustainability of forage and cereal systems, mainly for nitrogen enrichment of soils (Giambalvo *et al*., 2011). In mixtures, the different development of root and air systems and the legume's *rhizobia* activity can likely lead to a better use of nutritional and light resources, mostly due to the immediate nitrogen availability, thereby limiting its loss to the atmosphere. On the other hand, given the sensitivity of legumes at low temperatures, inclusion of grasses in mixtures allows animals to graze since late winter. Three trials, undertaken over a 14-year time span, from 2003 to 2016, studied a number of mixtures of *M.p.* Pratosardo and grasses compared to the respective pure stands rotations.

Materials and methods

Three trials were undertaken in Southern Sardinia (39°10' N, 9°06' E, 150 m a.s.l.) on a *Typic Calcixerept* soil (USDA, 2010), in order to study *M.p.* Pratosardo in pure stands and in mixtures with different grass species (Table 1), from 2003 to 2016.

Table 1. List of species and seed rate in brackets.

1 - Burr medic - *Medicago polymorpha* L. cv. Pratosardo (25 kg ha^{-1})[1]
2 - Annual ryegrass - *Lolium rigidum* Gaudin cv. Nurra (25 kg ha^{-1})
3 - Italian ryegrass - *Lolium multiflorum* Lam. cv. Teanna (25 kg ha^{-1})
4 - Oats - *Avena sativa* L. cv. Argentina (160 kg ha^{-1})

[1] Seed rate refer to pure stand and was halved in mixture.

In the first trial in 2003, *M.p.* Pratosardo was tested with *Lolium rigidum* Gaudin cv. Nurra, which in pure stands was N-fertilised at two levels: 0 or 40 units after each harvesting. The second 3-year trial, from 2007 to 2009, evaluated *M.p.* Pratosardo with *Lolium multiflorum* Lam. cv. Teanna, which in pure stands was N-fertilised with 40 units after each harvesting. In the third 5-year trial, from 2012 to 2016, *M.p*. Pratosardo was grown in stable intercropping (every year in the same plot) with *Lolium multiflorum* Lam. cv. Teanna or *Avena sativa* L. cv. Argentina and in a pure crop rotation without fertilisation (Vargiu *et al*., 2017). For all trials and years, sowing took place in November, in 10 m^2 plots with a randomised block design with three repetitions. Forage yield was evaluated by weighing the herbage of the whole plot cut at 10 cm height, with a sward height of 20 - 30 cm. Samples of 500 g were oven-dried to evaluate the percentage of dry matter. In the first year of the second trial (2007) and for all years in the third trial, samples of forage were analysed for protein and fiber content. Moreover, in the third trial, mixtures samples were also botanically separated to evaluate the land equivalent ratio (LER) (Mead and Willey,1980; Willey and Rao, 1980). Statistical analyses were performed separately for each trial using two-way ANOVA with MstatC.

Results and discussion

On the 14 year average, annual rainfall was 467 mm, irregularly distributed from October to May; winter temperatures seldom reached 0 °C and maximum temperature was 32 °C in July.

- First experiment - In 2003, since March, *M.p.* Pratosardo in pure crop or in mixture did not show significant differences with respect to N-fertilised annual ryegrass (Table 2).
- Second experiment - From 2007 to 2009, *M.p.* Pratosardo in mixtures did not show significant differences with respect to N-fertilised Italian ryegrass in pure stands (Table 3).
  Nutritional composition of *M.p*. Pratosardo showed a high protein content, 320 g kg^{-1} in the vegetative phase and 250 g kg^{-1} in the flowering phase and low fibre content, 80 g kg^{-1} in the vegetative phase and 150 - 180 g kg^{-1} in the flowering phase. These values were higher than those obtained with some annual clovers, such as *Trifolium alexandrinum* L., *Trifolium squarrosum* L. or *Trifolium incarnatum* L., studied in variety comparison trials in the same year and environment, with a protein content of 270 g kg^{-1} in the vegetative stage and 190 g kg^{-1} in the flowering phase, and a fibre content of 110 g kg^{-1} in the vegetative stage and 230 g kg^{-1} in the flowering phase.

Table 2. Forage production (Mg ha^{-1}) during 2003 and *M.p*. percentage in the mixture.[1]

Mixtures and pure crops	18 March	*M.p.* (g kg^{-1})	14 April	*M.p.* (g kg^{-1})	Total
M.p. Pratosardo	1.6 ^{a}		0.9 ^{ab}		2.5 ^{a}
Annual ryegrass cv. Nurra N = 0	0.7 ^{b}		0.4 ^{b}		1.0 b
Annual ryegrass cv. Nurra N = 100	1.3 ^{a}		1.1 ^{a}		2.4 ^{a}
M.p. Pratosardo + annual ryegrass	1.2 ^{a}	87	1.1 ^{a}	42	2.4 ^{a}
CV	29.4		28.1		17.3

[1] Means followed by the same superscripts are not significantly different at $P \leq 0.05$ (Duncan test).

Table 3. Forage production (t DM ha^{-1}) over three years.[1]

Mixtures and pure crops	2007	2008	2009
M.p. Pratosardo	5.2 ^{bc}	3.5 ^{c}	3.6 $^{a-c}$
Italian ryegrass cv. Teanna	6.8 ^{a}	3.7 ^{bc}	3.9 $^{a-c}$
M.p. Pratosardo + Italian ryegrass	6.3 ^{ab}	5.2 ^{ab}	4.2 ^{ab}
CV	12.8	17.3	17.0

[1] Means followed by the same superscripts are not significantly different at $P \leq 0.01$ (Duncan test).

N-fertilised pure stands of Italian ryegrass showed lower protein content, 170 g kg^{-1} in winter as pasture and 90 g kg^{-1} in spring as hay and a higher fibre content, 180 g kg^{-1} in winter and 270 g kg^{-1} as hay. *M.p.* Pratosardo in pure stands obtained the highest protein production per ha, 1.4 Mg vs 5.2 Mg of dry matter; in mixtures 1.0 Mg vs 6.3 Mg of dry matter.

- Third experiment - In each season of the 5 year trial, LER values underline the validity of mixtures in terms of forage yield (LER > 1) and protein production (Table 4).
  In *M.p.* Pratosardo, protein percentage falls from 310 g kg^{-1} to 210 g kg^{-1} in late flowering, while in grasses from 160 to 80 g kg^{-1}; in the same time, in *M.p.* Pratosardo fibre increases from 120 to 190 g kg^{-1} and in grasses from 190 to 280 g kg^{-1}.

Table 4. Average annual and seasonal dry matter yield (DMY) and protein yield (Mg ha^{-1}) of the five years of trial (2012 - 2016) and, in brackets, the percentage of *M.p.* in the mixtures.[1]

Mixtures and pure crops	Annual				Winter				Spring			
	DMY		Protein		DMY		Protein		DMY		Protein	
M.p. Pratosardo + ryegrass	4.3^{b}	(58)	0.85^{a}	(70)	2.1	(63)	0.49^{ab}	(74)	2.2^{c}	(44)	0.36^{a}	(50)
M.p. Pratosardo + oats	6.1^{a}	(30)	0.82^{a}	(40)	2.2	(20)	0.40^{ab}	(24)	3.9^{a}	(31)	0.42^{a}	(39)
M.p. Pratosardo	3.1^{c}		0.80^{a}		1.9		0.55^{a}		1.2^{d}		0.25^{b}	
Oats	5.7^{a}		0.59^{b}		2.0		0.33^{bc}		3.7^{ab}		0.26^{b}	
Italian ryegrass	4.4^{b}		0.43^{c}		1.5		0.22^{c}		2.9^{bc}		0.22^{b}	
					ns							
CV	12.6		13.8		14.4		14.5		10.5		9.6	

[1] Means followed by the same superscripts are not significantly different at $P \leq 0.01$ (Duncan test).

Conclusion

Our results highlight the advantage of burr medic/grasses mixtures in comparison with pure stands in terms of forage yield and forage quality. Moreover, these results show the effectiveness and the gregarious capacity of burr medic with respect to the grasses in mixtures. These features are not surprising since the burr medic cultivar Pratosardo has been collected and selected from a natural pasture with high biodiversity.

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Production capacity of forage legumes and persistence to root rot in organic mixed swards

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Abstract

Red clover (*Trifolium pratense* L.) is an important forage legume in Sweden, however, production is limited by the poor persistence often associated with injuries of root rot caused by several soil-borne pathogens. To identify sustainable legume crops persistence and production capacity of white clover (*Trifolium repens* L.), lucerne (*Medicago sativa* L.), birdsfoot trefoil (*Lotus corniculatus* L.) and red clover grown in mixed swards with timothy (*Phelum pratense* L.) was compared at two field experimental sites in a three year set up. Two or three harvests were taken with a forage harvester and total DM yields and the proportion of legumes was quantified. The prevalence of root rot was assessed in uprooted plants visually and fungal pathogens were quantified by real-time PCR (Polymerase Chain Reaction). Lucerne showed a competitive yield and high legume content in the first year ley (2016). Disease severity index (DSI) of the visual symptoms was significantly highest in red clover in the seeding year at both sites. Real-time PCR analyses showed prevalence of *Fusarium avenaceum*, *Phoma medicaginis* and *Cylindrocarpon destructans* in all tested legumes, thus indicating that, birdsfoot trefoil and lucerne show tolerance to the pathogens that cause root rot as their DSI were significantly lower compared to red and white clover.

Keywords: red clover, white clover, birdsfoot trefoil, lucerne, root rot, qPCR

Introduction

Red clover (*Trifolium pratense* L.) is primarily an important forage legume in milk production cultivated in mixed swards with grasses, but it is also a major green manure crop in organic farming. Yield and nitrogen fixation may be severely reduced over time due to infection by soil-borne fungal pathogens causing root rot and although it is a perennial species the plants rarely persist more than two to three years (Wallenhammar *et al*., 2008). Red clover plants are weakened by infection of *Fusarium avenaceum, Phoma medicaginis* and *Cylindrocarpon destructans* (Rufelt, 1986; Lager and Gerhardsson, 2002, Wessén, 2006, Öhberg, 2008, Almquist *et al*., 2016). No significant difference in persistence has been shown throughout several studies of cultivars of Scandinavian origin (Wallenhammar, 2010; Almquist, 2016). The objectives of our study were to compare yield and severity of root rot in red clover, white clover (*Trifolium repens* L.), lucerne (*Medicago sativa* L.) and birdsfoot trefoil (*Lotus corniculatus* L.) intercropped with timothy (*Phelum pratense* L.) over three years and to find a sustainable legume crop to produce high quality forage yields. This paper includes results from the seeding year and first harvest year.

Materials and methods

Field experiments were established in 2015 at Nibble, Järna (N 59° 19', E 18°4') and at Kvinnersta, Örebro (N 59°21'E 15°14'). Field plots (4.5 × 10 m) of red clover, white clover, birdsfoot trefoil and lucerne were sown individually in a mixture with timothy. The experiments had a randomised block design with four replicate blocks. Red clover cv. SW Vicky was sown at a seed rate of 8.0 kg ha^{-1}, white clover cv. Hebe at 4.0 kg ha^{-1}, birdsfoot trefoil cv. Oberhaunstedter at 10.0 kg ha^{-1} and lucerne cv. Marshall at 17 kg ha^{-1} in mixed plots with timothy cv. Lischka fixed at 8.0 kg ha^{-1}. The lucerne seed was inoculated with *Sinorhizobium meliloti* and the birdsfoot trefoil seed inoculated with *Rhizobium loti*. All plots were seeded with oats (*Avena sativa* L.; 200 kg ha^{-1}) as nurse crop established prior to the seed. All plots were harvested three times (3 June; 19 July; 16 August) Table 1, with a forage harvester at a height of 5 - 7 cm, except for plots of birdsfoot trefoil which were harvested twice (3 June and 16 August). Fresh weights were measured and the botanical composition analysed from a 500 g subsample from each plot. Dry matter yields were calculated on a 1000 g subsamples pre-dried at 60 °C for 24 h and thereafter, dried at 105 °C for at least 3 h. Ten roots were dug out per plot in late October and rinsed in running tap water. Visual assessment of root rot symptoms was performed according to Rufelt (1986). The roots were cut lengthwise with a scalpel and were assessed and classified as follows: 0 = no root rot or discoloring; 1 = the root is discoloured; 2 = minor root rot in parts of the root, the remaining part can be discolored; 3 = at least one third of the root is rotten, some of the plant shoots are dead and 4 = at least two thirds of the root is rotten, many of the plant shoots are dead. Disease severity indicies (DSI) were calculated according to Rufelt (1986). DNA was extracted from three roots per plot. Details regarding DNA extraction methods, primers, probes and qPCR analyses are described in Almquist (2016). Statistical analyses were performed by analysis of variance (ANOVA). Data was analysed using Tukey´s HSD.

Results and discussion

At Kvinnersta, red clover plots were damaged by wild boars during winter so the DM yield results at Kvinnersta are not discussed here. Dry matter yield in the first harvest year and the composition of legumes, grass and weeds at Nibble are shown in Table 1. The lucerne treatment produced the highest DM yield and was significantly higher than the white clover treatment. Dry matter content was significantly lower in the red clover treatment compared to all other treatments. Red clover and lucerne treatments showed significantly higher legume content compared to white clover and birdsfoot trefoil. The proportion of timothy was highest in the birdsfoot trefoil treatment mirroring the lowest content of legumes.

In the sowing year, visual assessment of roots showed, on average, significantly higher DSI (incidence of root rot) at Nibble (29.8) compared to Kvinnersta (7.8). At Nibble, the DSI for red clover was significantly higher, with a DSI score of 19.7 compared to the other legumes, where DSI ranged from 9.7 to 11.6. The results from the first ley year show an increase in DSI in accordance with results from previous studies (Wallenhammar *et al*., 2008).

Real-time PCR analyses (data not shown here) showed the presence of *Fusarium avenaceum*, *Phoma medicaginis* and *Cylindrocarpon destructans* in all legumes, indicating the presence of root rot in all legumes. However, DSI for red clover and white clover were significantly higher than DSI for birdsfoot trefoil and lucerne, thus indicating that birdsfoot trefoil and lucerne show a tolerance to the pathogens.

Table 1. Dry matter yield (t ha^{-1}), dry matter content (DM) of red clover, white clover, birdsfoot trefoil and lucerne with companion grass and composition of species at Nibble, Järna in the first harvest year (2016).[1]

	Forage yield (t DM ha-1)					Composition of species, average of 3 cuts			
	1st cut	2nd cut	3rd cut	Total	DM (%)	Sown legume	Other legume	Timothy	Weed
Treatments									
RC + tim	5,154	2,533^{b}	2,512^{a}	10,199^{ab}	15.6^{b}	49.5^{a}	9.2	29.8^{b}	8.3^{b}
WC + tim	5,145	2,509^{b}	1,419^{b}	9,073^{b}	19.2^{a}	36.9^{b}	0.0	47.1^{a}	12.5^{a}
BFT + tim	5,183	4,303^{*a}		9,486^{ab}	20.0^{a}	23.4^{c}	9.1	54.0^{a}	9.5^{b}
LU + tim	4,836	3,085^{b}	2,624^{a}	10,545^{a}	20.1^{a}	49.6^{a}	7.7	31.7^{b}	7.6^{b}
P-value	ns	< 0.001	0.003	0.030	< 0.001	< 0.001	ns	< 0.001	< 0.001
CV[1]	12,0	9.3	14.5	6.3	6.2	9.4	12.8	12.8	10.8

[1] *Harvest was performed later than the other treatments. 1st cut in all treatments: 3 June, 2nd cut in: RC + tim, WC + tim and L + tim: 19 July, 2nd cut in BTF + tim: 16 Aug, 3rd cut in: RC + tim, WC + tim and L +t im: 9 Sep. RC = red clover, Tim = timothy, WC = white clover, BFT = birdsfoot treefoil, LU = Lucerne. Different letters indicate significant differences according to Tukey's HSD-test ($P < 0.05$). [1]Coefficient of variation.

White clover improves its sustainability by a continuous development of new stolons. A successful establishment of lucerne with a new inoculant enabled growth during the following dry summer and promotes lucerne as an interesting legume crop of high productive capacity in a sustainable Swedish forage production system.

Conclusion

Root rot caused by different fungal pathogens contributes severely to a poor sustainability of red clover, particularly in fields where red clover is frequently grown as a forage crop. Birdsfoot trefoil and lucerne are interesting alternatives with a potentially higher persistence as shown in previous studies (Wallenhammar *et al.*, 2008). DNA analyses indicate that these species seem to tolerate the pathogens that are detected with qPCR in the roots.

Acknowledgements

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Perennial ryegrass (*Lolium perenne* L.) economic selection indices: are cultivar rankings valid under intensive grazing?

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Abstract

Economic based evaluation indices which rank cultivars on economic merit are available for perennial ryegrass. Economic values are applied to pasture performance data which are generally collected from small plot trials where cultivars may be sown as monocultures and managed under limited or no cattle grazing, with high levels of nitrogen fertiliser. This questions how cultivar rankings may change under more typical dairy farm management conditions. Spearman rank correlations were used to determine the relationship between cultivar economic merit rankings in the DairyNZ Forage Value Index (FVI) and cultivar rankings calculated using performance data from field trials managed under typical dairy cow grazing. The FVI is currently based solely on seasonal dry matter yield and, therefore, it is useful to determine the effect of including pasture metabolisable energy performance data on cultivar rankings. Results indicate that cultivar economic merit rankings in the FVI are consistent when cultivars are evaluated under dairy farm management conditions. The effect of including pasture ME performance data on cultivar economic merit rankings varied regionally.

Keywords: perennial ryegrass, cultivar evaluation, economic values, grazing

Introduction

Economic based evaluation indices are available for perennial ryegrass which apply economic values to pasture performance data generally collected from small plot trials. For example, in New Zealand, cultivar performance data in the Forage Value Index (FVI) is derived from the National Forage Variety Trials (NFVT) system where cultivars can be sown as monocultures and managed under limited or no cattle grazing and with high levels of nitrogen (N) fertiliser (Easton *et al.*, 2001). This raises the question of how cultivar rankings may change under more typical dairy farm management conditions where cultivars may be grown in association with white clover, managed with moderate levels of N fertiliser and subject to intensive dairy cattle grazing. The current FVI rankings are based on seasonal dry matter yield (DMY) only, although pasture ME content is considered an important pasture performance trait in dairy grazing systems (Chapman *et al.*, 2015). Therefore, it is useful to consider the impact of including pasture metabolisable energy (ME) on cultivar economic merit rankings. The objectives of this study were to assess the validity of current FVI cultivar rankings when cultivars are managed under typical dairy cow grazing and to determine the impact of including pasture ME on cultivar rankings.

Materials and methods

Seasonal DMY performance values were calculated for 21 perennial ryegrass cultivars from the NFVT system for two sites in New Zealand (Waikato and Canterbury). Cultivars included mid-, late- and very late-heading diploids and late- and very late-heading tetraploids. National Forage Variety Trial protocols were described by Easton *et al.* (2001). For each cultivar, seasonal DMY performance values were calculated relative to a genetic base (cultivars trialed prior to 1996) and cultivars were ranked on economic merit which was calculated using the method of Chapman *et al.* (2017) and the most recent economic values for seasonal DMY (Ludemann and Peel, 2017). These rankings were compared with economic merit rankings calculated similarly but using performance data from two field trials managed under intensive dairy cow grazing. The field trials were sown at two sites: DairyNZ Scott Farm, Waikato

(37°47S, 175°19E; altitude: 40 m a.s.l.; soil type: Bruntwood silt loam) and Lincoln University Research Dairy Farm, Canterbury (43°38S, 172°27E; altitude: 12 m a.s.l.; soil type: Wakanui silt loam over a mottled sandy loam phase). The Waikato site was non-irrigated while the Canterbury site received irrigation water as is standard for dairy farms in each region. At each site, the same 21 perennial ryegrass cultivars were sown in field plots with white clover in a row-column design, with four replicates. Plots were grazed by dairy cows when the average herbage mass across the trial area reached 2500-3200 kg DM ha^{-1}, to a target post-grazing height of 3.5-4.5 cm. From June 2013 until June 2016, DMY was estimated directly before each grazing by cutting one strip (1.5 m wide × 5 m long) from each plot by using a forage harvester (Haldrup GmbH, Ilshofen, Germany) set to a height of 5.5 cm above the ground. In year 2 and 3, representative samples of pasture (~150 g fresh weight) from each plot were collected at approximately every second grazing for estimation of ME content using near infrared spectrometry (Corson *et al.,* 1999). Pasture ME performance values were calculated for each cultivar relative to the genetic base (mid-heading diploid cultivars) for the relevant site and season. This allowed the economic merit of cultivars to be calculated from seasonal DMY and pasture ME, using the methods and economics values described by Ludemann and Peel (2017). The economic merit of each of the 21 cultivars was calculated using three sets of performance data at each site: (1) seasonal DMY from the NFVT trial system, (2) seasonal DMY from a field trial managed under intensive dairy cow grazing and (3) seasonal DMY and pasture ME from a field trial managed under intensive dairy cow grazing. Spearman rank correlations (r_s) were used to determine the relationship between cultivar economic merit rankings derived from the three sets of performance data.

Results and discussion

A strong positive relationship was found between cultivar economic merit rankings calculated from performance values obtained from the NFVT system and those obtained from field trials where cultivars were grown with white clover and managed under intensive dairy cow grazing at the Waikato (r_s = 0.79; Table 1) and Canterbury (r_s = 0.71) sites. These relationships indicate that the relative cultivar economic merit rankings in the FVI are consistent when cultivars are evaluated under typical dairy farm management conditions. This analysis corroborates the work of Ludemann *et al.* (2017) who ran probability simulations on seasonal DMY data collected from the same field trials and concluded that there was a high probability (> 94.9%) of high FVI rated cultivars outperforming low FVI rated cultivars. Using seasonal DMY and ME performance data from the Waikato and Canterbury sites, the relationship between cultivar economic merit rankings calculated from seasonal DMY performance data and those calculated from seasonal DMY and pasture ME performance data were determined. At the Waikato site, there was a very strong positive relationship between cultivar economic merit rankings derived from seasonal DMY performance data and those derived from seasonal DMY and pasture ME performance data (r_s = 0.96). The relationship at the Lincoln site, although also positive (r_s = 0.62), was weaker compared with the Waikato site. Variation in pasture ME between perennial ryegrass cultivars can be largely attributed to a broadening in the range of functional groups, i.e. increasing ploidy and the development of later-heading cultivars (Chapman *et al.*, 2015). At the Lincoln site, the changes in cultivar economic merit ranking with the inclusion of pasture ME performance data followed the expected differences between the functional groups; relative rankings of tetraploid cultivars tended to increase while the relative rankings of mid-heading diploid cultivars tended to decrease (data not presented). Wims *et al.* (2017) monitored trends in pasture ME at the Waikato site and reported that differences between the functional groups diminished over time due to changes in pasture botanical composition over time (decreasing perennial ryegrass content and increasing white clover and unsown species content) and between the groups. This probably explains why including the pasture ME performance data had little impact on cultivar economic merit rankings at the Waikato site. In contrast, the proportion of perennial ryegrass was relatively high for the duration of the field trial at the Lincoln site (> 0.70; data not presented). The results indicate that the effect of including pasture ME performance data in the FVI

Table 1. Spearman rank correlations between cultivar economic merit rankings calculated using performance data from field trials managed under intensive dairy cow grazing (field trial) and from the National Forage Variety Trial (NFVT) system for Waikato and Canterbury.[1]

Site		NFVT seasonal DMY performance data	Field trial seasonal DMY and pasture ME performance data
Waikato	Field trial seasonal DMY performance data	0.79	0.96
Canterbury	Field trial seasonal DMY performance data	0.71	0.62

[1] DMY = dry matter yield; ME = metabolisable energy.

will vary regionally, and that genotype × environment (G × E) interactions should be considered in the design of field trials to collect pasture ME performance data.

Conclusion

The strong positive relationship between cultivar economic merit rankings calculated from performance values obtained from the NFVT system with those obtained from field trials where cultivars were grown with white clover and managed under intensive grazing indicates that farmers can have confidence that current FVI rankings are valid under typical dairy farm management conditions with regard to seasonal DMY considerations. When expanding the scope of ranking systems to include ME, G × E interactions should be considered in the design of field trials to collect pasture ME performance data.

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Influence of silage making or haymaking on different protein fractions

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Abstract

For silage making or haymaking, the forage is first wilted and then ensiled or dried. These different processes influence the nutrient content, especially differences in the protein fractions. In a trial with forage from the first and third cuts of a ley, silage, barn-dried and field-dried hay were produced. At different stages (fresh grass, pre-wilted grass, silage and hay), samples were taken and five protein fractions were analysed. Fraction A is non-protein nitrogen, fractions B1, B2 and B3 have different solubilities and fraction C is insoluble. The specific degradation processes of the protein fractions began during wilting in the field. Silage fermentation had the highest effect on this degradation process. In comparison to fresh grass, fraction A increased in silage from the first cut by 127% and in silage from the third cut by 100%. For the barn- and field- dried hay, fraction A was on average 30% higher for the first cut and 11% for the third cut in comparison to the fresh-cut grass.

Keywords: protein fractions, wilting, silage, barn-dried hay, field-dried hay

Introduction

Proteolysis results in the loss of true protein, causing an increase in the concentration of the soluble non-protein nitrogen (N) fraction in grass silage. This process occurs during wilting of grass for silage or hay, but to a greater extent during the fermentation process in silages (Hoedtke *et al.*, 2010). Five different protein fractions, based on the characteristics of solubility according to Licitra *et al.* (1996), can be distinguished. A review investigated the effect of silage making on the different protein fractions (Hoedtke *et al.*, 2010). However, only a few results have been reported for haymaking (Resch and Gruber, 2015). The present study investigated the effect of wilting time and the two conservation methods, silage making and haymaking, on the different protein fractions.

Materials and methods

In 2015, grass from a ley harvested for the first and third cuts was used. The cutting date for the first cut was 10 May and the cutting date for the third cut was 8 July. The experiment was conducted at Agroscope in Posieux, Switzerland (latitude: 46°46' N, longitude: 07°06' E, altitude: 650 m). Samples of fresh grass, pre-wilted grass before ensiling, pre-wilted grass before barn drying and field-dried hay were taken at three different places in the same plot and analysed separately. During the wilting process, the forage was tedded several times. Additionally, after three months of conservation the samples were taken from the conserved forage. A total of 42 samples were analysed.

Near-infrared reflectance spectroscopy (NIRS) was used to analyse the nutrient contents (ash, crude protein [CP], acid detergent fibre [ADF], neutral detergent fibre [NDF] and ethanol soluble carbohydrates [ESC] of the samples (Ampuero Kragten and Wyss, 2014). Furthermore, according to Licitra *et al.* (1996), the protein fraction A (non-protein N), fractions B1, B2 and B3 with different solubilities, and fraction C (insoluble) were also analysed. Data were analysed using analysis of variance and the Bonferroni test (Systat 13).

Results and discussion

During the wilting period in the field, the DM content of the grass increased. The amount of CP was not significantly different (Table 1 and Table 2). The different protein fractions were significantly influenced by the wilting process (Table 1 and Table 2). In the present study, fractions A, B3 and C increased ($P < 0.01$) and fractions B1 and B2 decreased ($P < 0.01$), which is in contrast to the results reported by Edmunds *et al.* (2012), who found that fraction A decreased and fraction B2 increased during the wilting process.

The two silages had significantly higher CP content in comparison to the barn-dried and field-dried hay (Table 3 and Table 4). This fact can be explained by the ESC, which was significantly reduced during the fermentation process (data not shown). The fermentation process had an effect on the protein fractions. Fraction A increased in silage from the first cut from 32.6% to 73.9% ($P < 0.01$); in silage from the third cut it increased from 27.7% to 55.3% ($P < 0.01$) (Table 3 and Table 4). In comparison, in the fresh-cut grass, fraction A increased in silage from the first cut by 127% and in silage from the third cut by 100%.

This degradation process also impacted the other protein fractions B1, B2, B3 and C. In the first cut, statistically significant differences were found between silage and hay for B1, B2, B3 and C (Table 3). For the third cut, statistically significant differences were found between silage and hay for B2 and B3 (Table 4).

In comparison to fresh-cut grass, the protein fractions in the hay only changed slightly. For the barn- and field- dried hay, fraction A was on average 30% higher for the first cut and 11% for the third cut in comparison to in the fresh-cut grass.

Table 1. Dry matter, crude protein and the five protein fractions A, B1, B2, B3 and C content during the field-drying period of the first cut.[1]

	Day WT, h	DM %	CP $g\ kg^{-1}$	A %	B1 %	B2 %	B3 %	C %
Fresh grass	0–0	16.0^{a}	123	32.6^{a}	26.6^{a}	34.8^{a}	3.9^{a}	2.1^{a}
Wilted grass	1–22	27.2^{b}	135	31.7^{a}	18.4^{b}	34.1^{a}	13.1^{b}	2.7^{ab}
Wilted grass	2–49	51.3^{c}	134	36.0^{b}	14.9^{b}	28.1^{b}	17.6^{c}	3.4^{b}
Wilted grass	8–192	78.5^{d}	132	42.6^{c}	7.4^{c}	29.7^{b}	16.7^{c}	3.6^{b}
SE		0.91	5.8	0.42	0.86	0.59	0.43	0.18
P-value		< 0.01	0.50	< 0.01	< 0.01	< 0.01	<0.01	< 0.01

[1] WT: wilting time, DM: dry matter; CP: crude protein; SE: standard error.

Table 2. Dry matter, crude protein and the five protein fractions A, B1, B2, B3 and C content during the field-drying period of the third cut.[1]

	Day WT, h	DM %	CP $g\ kg^{-1}$	A %	B1 %	B2 %	B3 %	C %
Fresh grass	0–0	24.9^{a}	137	27.7^{a}	21.3^{a}	38.6^{a}	7.4^{a}	5.0^{a}
Wilted grass	0–4.5	42.0^{b}	142	26.9^{a}	14.7^{b}	37.9^{ab}	15.0^{b}	5.6^{a}
Wilted grass	1–28.5	81.9^{c}	131	33.5^{b}	13.2^{b}	34.4^{c}	13.6^{b}	5.3^{a}
Wilted grass	5–123.5	90.0^{d}	137	29.4^{a}	13.0^{b}	37.3^{b}	13.5^{b}	6.8^{b}
SE		0.49	2.9	0.71	0.48	0.23	0.81	0.19
P-value		<0.01	0.14	<0.01	<0.01	<0.01	<0.01	<0.01

[1] WT: wilting time; DM: dry matter; CP: crude protein; SE: standard error.

Table 3. Dry matter, crude protein and the five protein fractions A, B1, B2, B3 and C content of the silage, barn- and field- dried hay of the first cut.[1]

	Day	DM	CP	A	B1	B2	B3	C
		%	g kg^{-1}	%	%	%	%	%
Silage	92	25.3^{a}	154^{a}	73.9^{a}	1.7^{a}	18.9^{a}	3.1^{a}	2.4^{a}
Barn dried hay	92	88.5^{b}	127^{b}	41.0^{b}	7.3^{c}	33.4^{b}	15.5^{b}	2.8^{b}
Field dried hay	92	87.3^{b}	132^{b}	43.7^{b}	5.4^{b}	32.7^{b}	14.9^{b}	3.4^{c}
SE		0.64	4.8	0.65	0.38	0.56	0.37	0.21
P-value		<0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.05

[1] DM: dry matter; CP: crude protein; SE: standard error.

Table 4. Dry matter, crude protein and the five protein fractions A, B1, B2, B3 and C content of the silage, barn- and field- dried hay of the third cut.[1]

	Day	DM	CP	A	B1	B2	B3	C
		%	g kg^{-1}	%	%	%	%	%
Silage	90	39.9^{a}	152^{a}	55.3^{a}	5.7	27.5^{a}	6.0^{a}	5.6
Barn dried hay	90	89.2^{b}	139^{b}	31.7^{b}	9.3	38.0^{b}	15.1^{b}	5.9
Field dried hay	90	89.1^{b}	140^{b}	29.4^{b}	10.5	37.5^{b}	16.5^{b}	6.0
SE		0.46	1.9	1.16	1.31	0.78	0.41	0.31
P-value		<0.01	0.01	<0.01	0.09	<0.01	<0.01	0.58

[1] DM: dry matter; CP: crude protein; SE: standard error.

Resch and Gruber (2015) reported that fraction A only increased slightly in silage; however, in comparison to the present study, that study found higher proportions of fractions B3 and C as well as lower proportions of fractions B1 and B2.

Conclusion

Rapid wilting in good weather conditions reduces the degradation process of different protein fractions. Thus, the present study found that silage making has a greater impact on the protein degradation process than haymaking.

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Comparison of nutrient and mineral content of herbage from pasture and fresh indoor feeding

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Abstract

Grazing and/or indoor feeding of fresh herbage are common feeding systems for dairy cows in Switzerland. In the framework of an on-farm dairy production system comparison, the nutrient and mineral content of herbage from pastures and for fresh indoor feeding were regularly analysed during two growing periods. Nutrient contents (crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF), ethanol soluble carbohydrates (ESC)) were analysed by Near-infrared reflectance spectroscopy (NIRS) and the minerals calcium (Ca), phosphorus (P), magnesium (Mg), potassium (K), sodium (Na), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) determined using an inductively coupled plasma optical emission spectrometer. Due to the different utilisation, herbage for fresh indoor feeding contained lower proportion of grasses (60 vs 70%) and herbs (6 vs 9%) but a higher content of legumes (34 vs 21%). The nutrient content was more variable throughout the growing period in the herbage for fresh indoor feeding. The differences in species composition and the generally lower growth stage resulted in significantly higher CP and lower ADF contents of the pasture herbage. Herbage for fresh indoor feeding showed higher contents of Ca and lower contents of P and Zn. The Mg content was similar and increased from spring to summer. The data demonstrastes that herbage for fresh indoor feeding represents a valuable source of nutrients and minerals. Its contents, however, may fluctuate more strongly during the growing period as compard to herbage from pastures.

Keywords: herabage, grazing, indoor feeding, mineral content

Introduction

Grazing and/or indoor feeding of fresh herbage are very common feeding strategies for dairy cows in Switzerland. In this traditional system, easily accessible fields located close to the farm buildings are used for grazing while the herbage of more remote fields is harvested daily and fed fresh in the barn. This system allows the cows to be supplied with fresh herbage during the entire growing period. Due to climatic and other factors influencing plant growth and development, nutrient and mineral content of herbage may fluctuate strongly during the growing period. This can be of specific importance for fresh herbage for indoor feeding, which is cut on successive days with progressive developmental stages and which may differ in species composition as compared to herbage used for grazing. In the framework of an on-farm dairy production system comparison, the nutrient and mineral contents of herbage for indoor feeding were regularly analysed throughout the growing period and compared to the contents of herbage from pastures from a full grazing system.

Materials and methods

The system comparison (Reidy *et al.*, 2017) was conducted on the experimental farm of the Vocational Education and Training Centre for Nature and Nutrition in Hohenrain (620 m above sea level). In 2014 and 2015 from spring to autumn, herbage samples were taken directly from the pasture (full grazing) or in the barn from herbage (fresh indoor feeding). Samples were dried at 105 °C to determine dry matter (DM) content and at 55 °C for 24 h for nutrient and mineral content analysis. Prior to analysis, samples were ground using a mill (Brabender, Duisburg, Germany) equipped with a 1.0 mm sieve. Nutrient contents (crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), sugar) were analysed by NIRS. Dry ashed samples were solubilised in nitric acid 65% and their content of calcium (Ca), phosphorus (P), magnesium (Mg), potassium (K), sodium (Na), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) were analysed using an inductively coupled plasma optical emission spectrometer (ICP-OES, Optima 7300 DV, Perkin-Elmer, Schwerzenbach, Switzerland). Data were analysed using analysis of variance (Systat 13).

Results and discussion

Due to the different utilisation (cutting vs grazing), the herbage for fresh indoor feeding contained lower proportions of grasses (60 vs 70%, mainly ryegrass) and herbs (6 vs 9%) but a higher content of legumes (34% white and red clover vs 21% white clover only) than the herbage from the pastures. Despite the lower legume proportions, the CP content of the herbage from the pastures was significantly higher and both ADF and NDF contents were lower (Table 1). This might be related to the generally younger growth stage of the pasture herbage. From spring to autumn, an increase in the CP content was observed that was especially pronounced for the herbage from pastures (Figure 1). The highest ADF contents were found during summer for fresh herbage fed indoors. Crude protein and ADF contents varied considerably during the growing period and were much more pronounced for the herbage for fresh indoor feeding.

The Ca contents of the herbage for fresh indoor feeding were higher than from pasture herbage (Table 1). The highest values were found during summer (Figure 1). Lower contents were found for P, K and Zn in herbage for fresh indoor feeding. The contents increased from spring to autumn (Figure 1). The Mg contents were similar in the two different herbages and increased from spring to summer (Figure 1). Sodium, Cu and Mn contents were similar for the two herbages. Important variations were found for the Fe contents (Table 1). In comparison to the study of Schlegel *et al.* (2016), the values for herbage of the same botanical composition were similar for Ca, K and Cu, but higher for Na and Fe and lower for Mg, Mn and Zn.

Table 1. Nutrient and mineral content of herbage from pasture and fresh indoor feeding.

		Pasture		Indoor feeding		*P*-value		
		2014	2015	2014	2015	Herbage	Year	H × Y
CP	g kg^{-1}	236	257	166	192	< 0.01	<0.01	0.76
ADF	g kg^{-1}	227	214	288	254	<0.01	<0.01	0.13
NDF	g kg^{-1}	405	415	441	409	0.14	0.28	0.04
Sugar	g kg^{-1}	101	91	93	108	0.47	0.66	0.03
Ash	g kg^{-1}	113	115	114	112	0.83	0.86	0.62
Ca	g kg^{-1}	5.8	6.6	9.2	10.5	< 0.01	0.07	0.69
P	g kg^{-1}	4.9	4.6	4.0	3.9	< 0.01	0.12	0.34
Mg	g kg^{-1}	1.9	2.2	2.2	2.2	0.21	0.24	0.36
K	g kg^{-1}	39.2	37.1	34.7	31.1	< 0.01	< 0.01	0.44
Na	g kg^{-1}	0.4	0.3	0.5	0.4	0.02	<0.01	0.99
Cu	mg kg^{-1}	12	12	11	11	0.06	0.60	0.73
Fe	mg kg^{-1}	365	263	619	162	0.47	0.01	0.09
Mn	mg kg^{-1}	56	57	57	50	0.44	0.44	0.33
Zn	mg kg^{-1}	33	37	26	28	< 0.01	0.02	0.67

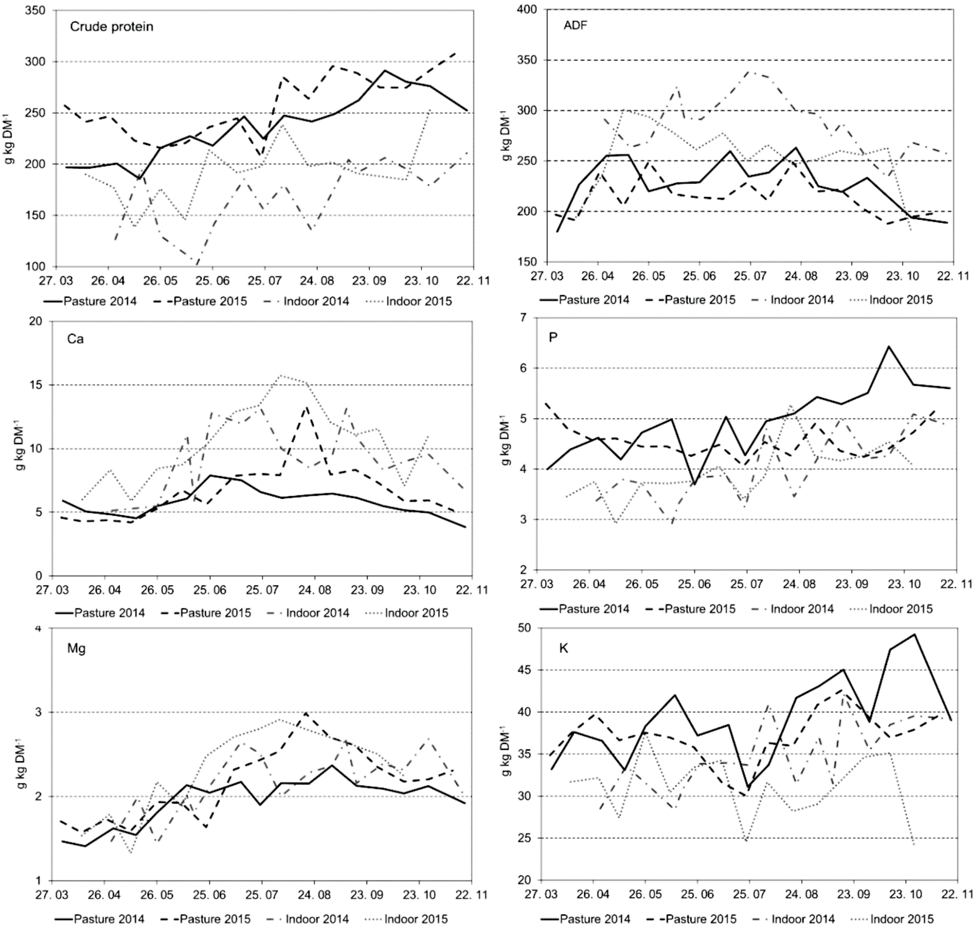

Figure 1. a-f: Crude protein, ADF, Ca, P, Mg and K contents during the two growing periods 2014 and 2015.

Conclusion

The results demonstrate that differences in species composition and more adavanced growth stages of herbage for fresh indoor feeding result in lower CP and ADF contents as compared to herbage from pastures. Despite considerable seasonal fluctuations, which are more pronounced in herbage for fresh indoor feeding, Ca, P, K, Cu, Fe and Mn may cover the mineral requirements for dairy cows (Agroscope, 2017). Due to the lower content of Mg, Na and Zn, these minerals should be supplemented.

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Theme 2.
Appropriate livestock for grasslands, key characteristics of animals adapted to and suitable for grasslands

Robust animals for grass based production systems

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Abstract

A characterisation of dairy, beef and sheep best suited to profitable/sustainable production within the context of European [semi] intensive pasture-based systems will be conducted. To deliver optimal performance, pasture must be managed effectively, but pasture-based systems are less energy intensive and are climate sensitive. This induces challenges and constraints not normally posed to animals in intensive feeding environments and emphasises the importance of animal traits associated with robustness and adaptive abilities. A survey of French dairy farmers concluded that a robust cow is a 'transparent' cow with a long lifetime. The traits required under grazing include: efficient converters of feed to product, such as high milk yield or milk solids (dairy) or meat yield/weaning weight (beef/sheep), good functionality, healthy, reproductively fit and finally, exhibiting longevity. Unique to successful grazing, is a capability to achieve large intakes of forage to meet productive potential and an ability to adapt to fluctuating feed supply. In seasonal systems, grazing ruminants will be expected to conceive and give birth at the appropriate time each year, usually within 365 days. The optimum breed or strain will differ, based on local management constraints and objectives. However, general principles do apply and recommendations will be made based on this review with regard to the traits of interest for pasture-based production.

Keywords: robustness, grass based system, grazing, selection

Introduction

As a consequence of the increasing world food demand associated with the growth of the human population, the future requires promotion of more efficient, sustainable livestock systems, and the use of greater proportions of non-human competitive products to feed farm animals. The ruminant's natural ability to consume forages and sub-products and to produce high quality human food helps to develop and improve forage based systems. Within these systems, grass-based systems using preferential grazing as animal feed, are viewed as economically and environmentally optimum. In temperate areas, well managed grazed grass is the unique forage which is correctly balanced to meet the nutritional requirements of both large and small ruminants.

In the context of this paper, pasture-based systems may be characterised as systems where the primary feed source is grazed grass (typically ≥60% of the diet). The extent and efficiency with which grazed pasture is maximised will vary across Europe. Intensified pasture-based systems such as that practiced in Ireland are characterised by long term permanent pastures, the application of grazing management practices to maximise pasture production and quality in combination with relatively high stocking density to result in high milk solids or carcass production per unit area. Less intensified pasture-based systems, more typical of France, tend to be associated with a greater diversity environment; multispecies pastures (some with clover) or natural grasslands, seasonal climatic extremes, and availability of high quality alternative feeds. Common, however, is a lower cost of production, system resilience and environmental sustainability (O'Donovan and Delaby, 2016). A further advantage is greater societal acceptability as a 'friendly livestock system' (Cardoso *et al.*, 2016). However, all of these advantages of grass-based systems are only effective if the characteristics of the dairy, beef and sheep breeds can match the requirements and limits of such systems.

The objective of this synthesis paper is to highlight such specificities and to outline the key animal characteristics required by robust cattle and sheep in pasture-based systems.

A brief background to grass-based system specificities

Pasture-based systems are generally more constraining, less stable and more uncertain than indoor based systems, whereby, the system is designed to serve the animal. In pasture-based systems, the reverse is true. The system is such that the animal is faced with natural irregularities or antagonisms, e.g. inclement climatic conditions, parasitic agents, etc. As the animal is *de facto* an integrated part of the system, the animal is expected to contribute to its ability to face environmental variability and hazards, known as robustness. Genetically robust dairy cows are less sensitive to sub-optimal circumstances (Veerkamp *et al.*, 2013). In a recent paper Friggens *et al.* (2017) proposed a generic definition of animal robustness as '*The ability, in the face of environmental constraints, to carry on doing the various things that the animal needs to do to favour its future ability to reproduce*'.

In contrast to dairy cattle where only about 10% of the world's milk production is from grazing systems, beef and sheep are primarily managed under grazing. Consequently, in general, different strains of individual beef or sheep breeds have either not evolved from selection in different production environments, or they have not spread outside of their original geographical area (Buckley *et al.*, 2005). Dairy cows that are optimal in a pasture-based system of production share many general characteristics with cows that are appropriate for a non-pasture system. However, the relative importance of traits can differ (Washburn and Mullen, 2014). Nutrient demand intentionally coincides with seasonal forage availability, fertility is emphasised, as generally does selection for high milk fat and protein content. Similar principles apply to beef and sheep where production is also chiefly based on the efficient conversion of grass to meat. As with seasonal pasture-based dairying, efficiency is optimised when beef cows/ewes give birth in spring with increasing herd/flock demand matched by increasing pasture supply.

Ability to adapt to grazing

Maximising grass intake is a key characteristic in grass-based systems (Delagarde *et al.*, 2001). Feeding behaviour is inextricably linked to the nature of the feed on offer and the circumstance by which the feed is presented (Prendiville *et al.*, 2010). Systems based on grazed pasture intrinsically limit nutrient intake compared with indoor total mixed ration (TMR) diets. This is evident from studies conducted in the USA by Kolver and Muller (1998) who suggested a 20% decrease in daily intake with pasture-fed cows. A similar result was observed in Ireland by Kennedy *et al.* (2003) and Horan *et al.* (2006) where Holstein cows highly selected for milk volume were not capable of eating enough to satisfy the demand associated with the milk potential. The study of Prendiville *et al.* (2010) related feeding time of lactating dairy cows in their pasture-based study with comparable feeding times in a TMR-based indoor study (Aikman *et al.*, 2008). Apart from environmental, plant and management factors (Dillon, 2005), milk production from pasture is limited by the ability of the grazing animal to consume sufficient quantities of herbage (Stakelum and Dillon, 2003). Increased grass allowance induces higher levels of grass intake but also higher levels of refusals and decreases pasture utilisation (Delaby and Horan, 2017; Pérez-Prieto and Delagarde, 2013). Therefore, a balance must be achieved between performance on a per animal and per hectare basis (McCarthy *et al.*, 2011). Effective pasture management enforces a limited grass allowance, balancing the dual objectives of generous feeding to achieve performance and high levels of pasture utilisation, thus optimising farm profitability (Penno, 1998).

A study in beef cattle by Goodman *et al.* (2016) on rangeland pastures has observed behavioral adaptation to the decrease in food availability. Across two diverse temperament profiles, beef cows classified as fast eaters when indoors were shown at grazing to spend less time close to the drinker and to explore a larger area of the pasture. They were considered to express a 'go getters' temperament. In contrast, slow eaters cows expressed a 'laid back' temperament. Interestingly, the two contrasting temperament profiles were shown to be positively correlated to animal performance with 'go-getters' showing shorter return to estrous after calving and heavier calf weaning weights than 'laid-back' cows. These findings are in line with Prendiville *et al.* (2010) who showed that cows with higher production efficiency were more aggressive grazers. Pryce *et al.* (2005) observed that dairy animals that are lighter are capable of superior productivity within intensive pasture-based systems because of their lower maintenance requirements and higher production per unit of feed consumed. An ability to achieve large intakes of forage relative to their productivity potential should also confer an increased likelihood of survival, another integral component of optimal financial performance (Lopez-Villalobos *et al.*, 2000).

Ability to cope with variability of grass resources and to rebound

As grazing systems are subjected to the external environment, animals may be exposed to unpredictable disturbances from the external environment (severe climate, predation, diseases; Mirkena *et al.*, 2010). Animals react to such perturbations by initiating adaptive responses that may alter phenotype, physiology and/or behaviour. These adaptive responses rely on underlying adaptive mechanisms that will support the ability of the animal to withstand and/or rebound from perturbation (resilience or indeed robustness). Such adaptive mechanisms were reviewed in several papers (Blanc *et al.*, 2006; Mirkena *et al.*, 2010; Mulliniks *et al.*, 2016) that outlined the key roles of metabolic flexibility, nutrients allocation, body reserves, behavioural strategies and temperament to explain the diversity in the ability to rebound. In grass-based systems, deviations in productive or functional traits are tolerated when animals are experiencing disturbances provided that they can react quickly when conditions become favourable again. For example, as described by Blanc *et al.* (2007), 40% of the ewe lambs that experienced severe under nutrition from three to nine months were still not cycling at nine months of age. But after the introduction of *ad libitum* feeding, they reached puberty within a three week period and could be used for breeding. Such an ability to rebound is also observed for other life functions like growth (compensatory growth in heifers; Hoch *et al.*, 2003) or lactation as observed on the milk yield in a ten day residence time grazing paddock (Roca-Fernandez *et al.*, 2012).

In temperate climates, grass growth is seasonal with maximum growth observed in spring (between mid-April and late May; Northern Hemisphere), a variable decrease in summer and minimum or no growth observed in the winter months. This aspect is well illustrated with the four regional French and Irish grass growth profiles simulated with the 'Moorepark St Gilles' grass growth model (Figure 1a and b; Ruelle *et al.*, 2018). This typical profile has large consequences on the feed resources available to animals, with an excess of grass often observed in spring and a deficit in winter. The summer period is probably the most variable period according to the latitude in Europe and depending on local temperature and rain regularity.

Coupled with the seasonality in grass growth, is the unstable nature of the nutritional value of grass, which changes firstly with the season, the age of regrowth and the phenological stages. Leafy grass or legumes in spring are characterised by a high nutritive value, in terms of energy, protein content and also voluntary intake. Although at this time the grass is highly palatable, the ratio between the grass energy content to the fill unit value, named energy density, can be too low to match a lactating animals energy demand. Matching the animal demands with grass only in the spring months can be a real challenge. With conserved grass, hay or silage not supplemented with concentrate, the feeding situation may be worse and can result in energy deficit periods as shown in Figure 2. This is particularly important for dairy cows

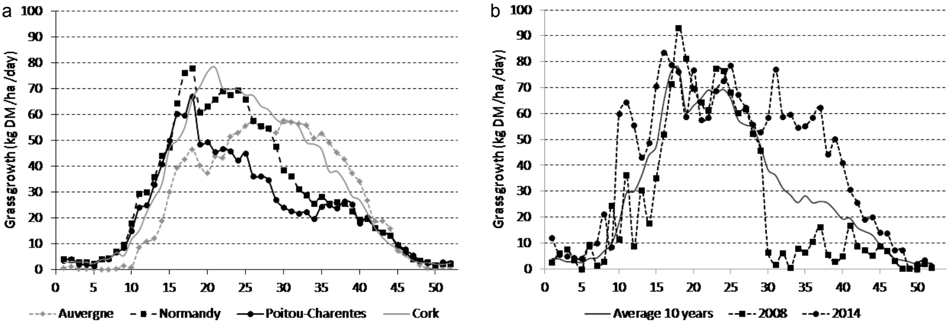

Figure 1. Annual grass growth profile according to the geographic localisation in France and Ireland (a) and the year in Normandy (b). On an average for 10 years (Figure 1a), the grass growth profile of a same type of pasture with the same level of N mineral applied differs because altitude, rain, temperature and light differ. The grass growth starts early in Ireland (Co Cork - Fermoy - 52°08 N / 8°16 W), later in upland (Auvergne - Marcenat - 45°18′ N / 2°49′ E) and is higher in summer than in Normandy - Le Pin (Lowland - 48°44′ N / 0°08′ E) or in Poitou-Charentes - Lusignan (Lowland - 46°26′N / 0°07′ E), region with higher temperatures in summer and mainly less regular rains. Within a region, the average profile is also highly variable between years, week per week, due to the highly variable climatic conditions (Figure1b).

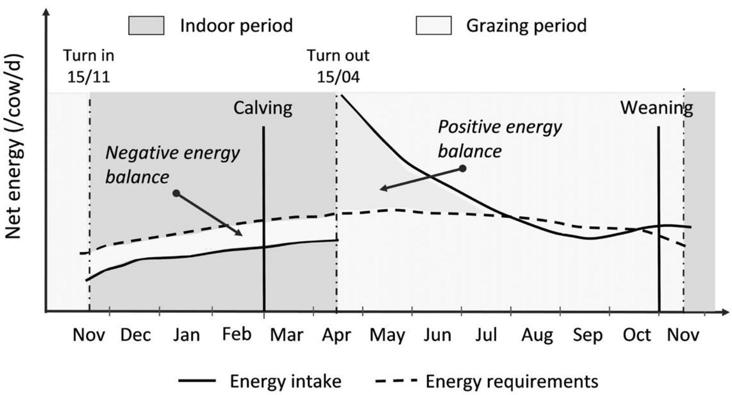

Figure 2. Changes in net energy requirements (dotted line) and energy intake (solid line) of beef cows in a winter calving system in France. Energy balance is negative during all the indoor building period because of low energy density of hay and increasing energy requirement from the end of pregnancy and early lactation. Energy balance becomes positive since cows are turned out and graze (Institut de l'Elevage, 2015)

in early lactation at grazing (Peyraud and Delagarde, 2013) or for suckling cows and ewes at the end of gestation when fed with poor quality forages indoors in winter.

In these conditions, the challenge for the ruminant female is to maximise grass or forage intake and where deficits in energy requirements exist, the ruminant must be able to react and limit the consequences of this imbalance. This imbalance between the grass energy supply and the energy demand of the lactating beef cow rarely occurs due to the relatively low milk production potential of the cow and milk yield demand of the often single suckled calf. However, for ewes rearing high litter sizes and managed at high stocking rates, coupled with the low energy supply of grass can have a knock-on effect on lamb growth rate and the number of days to slaughter for individual lambs (Earle *et al.*, 2017a). Such physiological energy deficits resulting from high requirements concomitant with limited intake capacity have been exacerbated by genetic selection for productive traits such as milk yield in the North American Holstein (Kolver and Muller, 1998) and selection for high prolificacy levels in ewes (Safari *et al.*, 2005). This is well illustrated in the INRA Le Pin experiment where Holstein cows turned out at grazing with only 3 kg of concentrate DM after a nine to 11 weeks early lactation indoor winter feeding period. The Holstein cows with a greater milk yield potential had greater observed milk yields at the peak of lactation in winter and during all the spring grazing period. However, they also expressed a greater decline in the milk yield six and 12 weeks post-turnout (Table 1).

To cope with nutritional challenges resulting from changes in both seasonal grass availability and quality and changes in animal nutritive requirements, animals must be able to store body reserves when feed conditions are favourable and to mobilise them in limiting feeding conditions. Cows that can maintain a higher body condition score may have an advantage in pasture systems because they can draw upon body reserves if feed is limited (Pryce and Harris, 2006). As described by Delaby *et al.* (2010), the body condition score losses, reflecting body tissue mobilisation in early lactation, are higher in Holstein cattle with high genetic merit for milk yield and in low feeding levels compared with Normande low genetic merit for milk yield and high feeding levels. These observations were also reported by Roche *et al.* (2006) comparing North American or New Zealand Holstein cows with or without concentrate supplementation at grazing and by Dillon *et al.* (2006) within Irish experiments comparing different dairy breeds. An on-going sheep study in Ireland (McGovern and McHugh, 2017) has shown that greater body reserve mobilisation in early lactation is observed in ewes of high genetic merit for maternal traits relative to ewes of low genetic merit for maternal traits in a grass-based system. On an annual basis, the animal must be able to limit the consequence of poor condition score (energy balance) on other functions such as fertility, sensitivity to disease, and ultimately, longevity. But in reality, in both cows and high prolificacy ewes early in lactation, control of body reserve mobilisation is very difficult as it is highly associated with genetic merit (Walsh *et al.*, 2008) and the body condition score at calving or lambing.

Ability to reproduce and achieve compact parturition

One of the main objectives of grass-based ruminant producers is to be at least self-sufficient in forages and if possible to be totally feed self-sufficient. At farm level, in grass-based systems, the first factor to determine the level of self-sufficiency is the global stocking rate (i.e. the number of cattle or sheep that can be fed on the farm area). The optimum stocking rate will be highly dependent on the local agro-climatic potential. Secondly, a producer must match herd/flock demand to the seasonality of grass availability (Butler, 2014; Delaby and Horan, 2017; Earle *et al.*, 2017a). In ruminant production, the maximum energy demand usually occurs in the period immediately pre-parturition and during the weeks following parturition when milk production reaches its peak. Consequently, the optimal grass-based system parturition should occur in the weeks prior to high grass availability. Seasonality of reproduction in small ruminant species is a natural adaptation to the annual pattern of grass resources availability; in bovines, reproduction can occur at any time within the year.

Table 1. Effect of milk potential (evaluated with the peak of lactation) on milk and body condition score changes during the spring grazing period (adapted from the INRA Le Pin 2006-2015 experiment).

	Milk yield (kg day^{-1})				Body condition score [0 to 5]		
	Peak of lactation	At grazing turnout (lactation days)	6 weeks after turnout	12 weeks after turnout	At calving	At turnout	12 weeks after turnout
Primiparous							
> 35 kg at peak	39.8	35.9 (74)	30.5	25.3	3.25	2.50	2.10
< 35 kg at peak	30.6	28.4 (78)	25.6	21.9	2.85	2.60	2.40
Multiparous							
> 45 kg at peak	51.0	45.7 (60)	36.1	30.6	2.85	2.25	2.00
< 45 kg at peak	40.4	35.8 (66)	31.5	26.1	2.60	2.40	2.25

Reproduction performance is one of the most important determinants of production efficiency and genetic gain in most dairy production systems (Esslemont and Peeler, 1993). The use of minimal supplementation coupled with seasonal calving requires cows that are reproductively efficient and adapted to obtain most of their nutritional needs from pasture (Washburn and Mullen, 2014). It is generally accepted that Holstein cows highly selected for milk yield are not suited to seasonal pasture-based systems due to reduced body condition score and inferior reproductive performance (Dillon *et al.*, 2006 – Table 2).

Furthermore, in order to maximise reproductive performance and lifetime production efficiency, heifers must conceive at around 15 months and calve by 24 months of age (Heinrichs and Hardgrove, 1987). In seasonal production systems, the relative importance of age at puberty is greater than in confinement and year-round calving systems. To achieve seasonal targets, an early onset of puberty is critical (Archbold *et al.*, 2012). Breed differences do exist suggesting differences in suitability for intensive compared with less intensive pasture-based dairying and indeed, beef production. The findings of Archbold *et al.* (2012) indicate that Jersey × Holstein-Friesian heifers are earlier to mature than Holstein-Friesian heifers, whereas, continental breeds like Normande or Montbeliarde are a little bit later maturing. Larger European beef breeds were shown to grow faster to heavier mature weights, but reach puberty at older ages and have lower reproductive efficiency, especially in less favourable conditions (Morris *et al.*, 1993).

In countries or regions where the rain is evenly distributed across the year (40 to 60 mm monthly) and grass growth occurs in summer, the ideal parturition period is in spring (Figure 3). Spring turnout dates should be adapted according to the start of grass growth and will be later in northern compared with southern Europe, or in uplands compared with lowlands. For cattle, a compact calving period in spring allows peak grass growth to coincide with the lactation period. For sheep, the shorter lactation period (three months) allows for high stocking rates to be achieved during the highest grass growth period in the year. Moreover, during this period (i.e. spring and early summer), the grass nutritive value matches the animal nutritional requirements. An additional benefit of calving in the spring for dairy and beef cows is that the dry off period coincides with winter when grass growth ceases and conserved forages can supply the lower nutritive requirements of the animal. In regions with frequent drought periods in summer, two parturition periods occurring at six monthly intervals may be optimal (Pottier *et al.*, 2007 – Figure 3).

Table 2. Reproductive performance observed in the INRA Le Pin experiment (The cow for the system? - 2006-2015) and in the Teagasc NGH experiment (Next Generation Herd – 2013-2016) in comparison with the objective for grass-based dairy system and compact calving management (12 weeks calving period).

	Target	**The cow for the system?[1]**				**NGH[2]**	
Feeding level		**High**		**Low**		**NatAv**	**Elite**
Breed		**Holstein**	**Normande**	**Holstein**	**Normande**		
Milk yield (kg)		8,660	6,000	6,230	4,670	5,610	5,410
BCS at calving (pts [0 to 5])		2.85	3.50	2.65	3.10	2.75	2.90
BCS losses (pts [0 to 5])	0.50	-1.00	-0.60	-1.20	-0.85	-	-
Interval calving - 1st ovulation (days)	25 to 30	41	33	39	30	-	-
Normal cyclicity profile rate (%)	80	48	65	44	77	-	-
First AI in-calf rate (%)	60	33	43	28	38	46	61
6 week in-calf rate (%)	70	41	46	35	51	58	73
13 week in-calf rate (%)	90	60	73	55	68	81	92

[1] High: In winter (100 days), early in lactation, total mixed ration with maize silage, dehydrated alfalfa and concentrate, *ad libitum*. At grazing (180 days), 0.35 ha per cow, 4 kg concentrate and 5 kg maize silage from July. In autumn (85 days), 5 kg maize silage, 4 kg concentrate and grass silage *ad libitum*. Low: In winter (100 days), early in lactation, total mixed ration with grass silage and big bale haylage, *ad libitum*. At grazing (180 days), 0.55 ha per cow. In autumn (85 days), grass silage *ad libitum*. No concentrate.

[2] Two genotypes based on Ireland's dairy selection index, the Economic Breeding Index (EBI): NatAv (n = 45 annually) representing national average based on EBI and Elite (n = 90 annually) representing the top 1%.

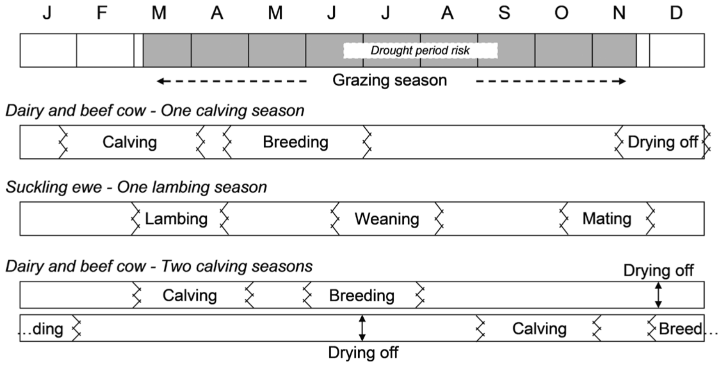

Figure 3. Grass-based system management recommendations for cattle and sheep according to the grazing season length and the risk of drought period in summer (Delaby and Horan, 2017; Earle *et al*, 2017a; Pottier *et al*, 2007).

According to the area of the grazing platform, the herd proportion assigned to calve in one period can be split 50/50 or 66/33, respectively in spring and autumn.

Compact calving or lambing require a strictly managed compact breeding period and excellent fertility performance. This demands a return to cyclicity to coincide with the commencement of the breeding season and to successfully achieve pregnancy within a limited breeding period of 3 months for cattle and 1.5 months for ewes. In one-lambing-per-year sheep farming systems, reproduction occurs in the post-weaning period, whereas in the case of both beef and dairy cows, reproduction occurs during early lactation. Ewes have a greater chance to recover body reserves prior to mating thereby increasing their ability to maximise prolificacy (i.e. litters of multiples). As prolificacy is one of the most important criteria of the lamb production system efficiency (Earle *et al.*, 2017b); maximising litter size or prolificacy is a function of the genetic strain (Dawson and Carson, 2002) and also the body reserves ('flushing') at mating (Coop *et al.*, 1966). In beef cattle, when the breeding season occurs at grazing, the increase in feeding level improves the energy status of the cows, thereby reducing the period to cyclicity, specifically in thin cows (Friggens *et al.*, 2017). The dairy cow situation is more complicated as a consequence of the high nutrients demand for lactation at this period (Friggens *et al.*, 2010) and impacts a cascade of fertility characteristics. To obtain good reproductive performance, the luteal activity has to be restored and regular, the oestrus and heats should be well expressed and easy to detect and after AI, the conception should be effective and the embryo implantation success to re-calve (Bedere *et al.*, 2017a and 2017b). This defines the proprieties of a robust cow according the objective of compact calving.

Ability for maternal care and to stay healthy

During parturition, another important robustness characteristic of dairy, beef and sheep is the ability to deliver a viable offspring. Increased dystocia at parturition (caesarian, vaginal tearing) has a negative impact on subsequent reproductive performance, especially in cattle (Meijering, 1984). Levels of dystocia must also be minimised to reduce labour requirements at parturition and also to provide a favourable perception to consumers of grass-based production systems. Maternal care traits such as mothering ability or progeny suckling ability are also of importance to ensure low levels of calf or lamb mortality in all systems but especially in extensive systems (Macfarlane *et al.*, 2010).

A survey of dairy farmers (Ollion, 2015) where farmers were asked to define a robust cow, 80% of farmers answered a '*cow with no problems, never sick, who doesn't need to see the veterinarian*'. In terms of health, three traits are specifically relevant to grass-based systems. The first key characteristic is the ability of the animal to cope with parasite burdens. Parasite burden is a major issue in grass based systems as, when not controlled it can have negative effects on productivity and when anthelmintic treatments are used questions are raised in relation to its impact on the environment as well as anthelmintic resistance. At the animal level, genetic selection to reduce parasite burdens can be achieved (Moreno-Romieux *et al.,* 2017; McHugh *et al.*, 2014). Animals on grass-based systems are also more susceptible to the effects of inclement weather and grass nutrient imbalance (excess of nitrogen, minerals), and are therefore at greater risk of metabolism or digestive disequilibrium such as bloating, grass tetany and also for ewes, pregnancy toxemia. Such nutritional disorders are often lethal and therefore, non-occurrence is a necessity. The last major problem for grazing systems concerns feet and leg diseases. Dairy cows must walk to the milking parlour two times per day, therefore lameness is a common occurrence. In addition, lameness in sheep, often characterised by scald or footrot is common within grass-based systems (O'Brien *et al.*, 2017). Lameness, in either sheep or dairy cows, has a negative impact on the animal's ability to graze, thereby reducing energy intake and thus, milk or growth performance as well as reproductive performance.

A robust animal must be a multi-functional animal

Robustness is a multi-factorial trait and relies on the ability of the ruminant female to be able to assume the highlighted productive and functional expectations, to cope with constraints and be resilient to disturbances. Recently, Ollion *et al.* (2016) performed multivariate analysis to explore the diversity in the ways cows prioritise between life functions (milk yield, body condition change and reproduction success) in early lactation (time when dairy cows are experiencing an energy deficit). The concept of dairy cow profiles developed in this study helps to describe different types of cows beyond the breed effect. This method has been applied on the INRA Le Pin experiment (Cloet *et al.*, 2015) and four profiles with specific trade-offs have been highlighted (Figure 4). Some cows prioritise milk solids yield without a detrimental effect on reproduction (cluster 1) while others are less efficient with regard to fertility without compensating in milk solids (cluster 2) or are unable to compromise (cluster 4). Clearly, cluster 3 appears to be more in accordance with compact calving grass based systems with priority given to reproduction

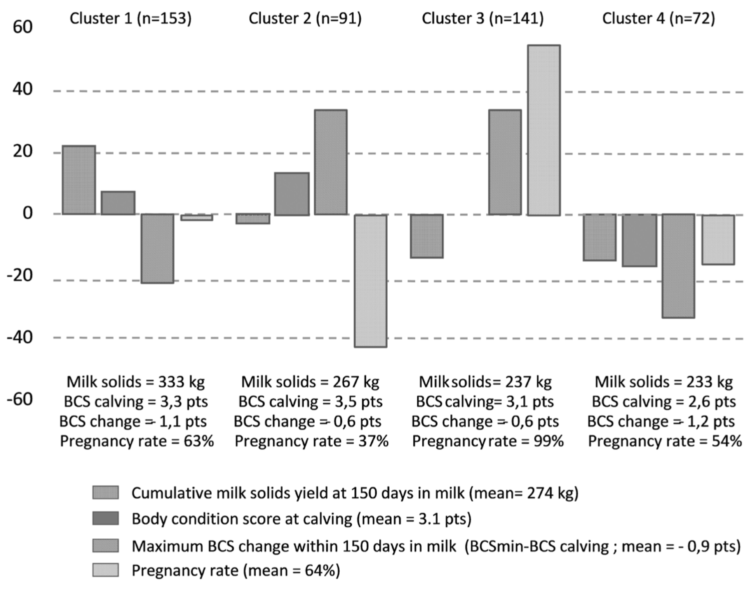

Figure 4. Expression profiles of priorities between milk solids yield, body condition score and pregnancy rate of Holstein and Normande cows. Deviations are expressed in relative proportion (%) of the mean value observed for the 457 lactations clusters of lactation profiles were identified by multivariate analysis followed by clustering analysis. Values between brackets are number of lactations in each cluster.

(pregnancy rate = 99 vs 64% on average) and maintaining body condition without impairing milk solids yield. It is possible to hypothesise that such differences between profiles are associated with a diversity in nutrient acquisition (forage intake capacity) and or in nutrient allocation (Friggens *et al.*, 2017).

Genetic improvement programmes should use a selection index that combines all the economically important traits appropriately for the local conditions and systems (Buckley *et al.*, 2005). An excellent example of success in this regard is the Irish Economic Breeding Index (EBI). Both genetic trends from the national population (Figure 5) and the most recent results from a controlled experiment at Teagasc Moorepark, 'Next Generation Herd' (Table 2) are illustrations of the consequence of a better agreement in the selection criteria and producer goals (Buckley *et al.*, 2017). Experimental evidence from studies in beef and sheep also indicate that selection of females based on their genetic merit for maternal type traits may result in the selection of a more robust female for grass-based systems (McCabe *et al.*, 2016; McGovern and McHugh, 2017). A 'better balance' may also be obtained by crossbreeding (Buckley *et al.*, 2014; Coffey *et al.*, 2016; Dezetter *et al.*, 2015) due to a combination of both breed complementarity and heterosis.

This concept of a well-balanced animal is well expressed by grassland farmers in response to an open multi-answer survey realised by Ollion *et al.* (2015) and presented in Ollion *et al.* (2018). The question was 'What is a robust cow to you?' The first trait (80% of farmers speak about) cited by farmers was good health (never sick, no veterinary need) followed by morphology with 64% (solid legs, able to go grazing, good udder). The third trait quoted (33%) concerned reproductive function with an ideal of one calf every year. Intake capacity, milk yield and temperament closed the list, cited by 18 to 20% of the farmers. Besides quoting functional, productive or behavioural traits, farmers also characterised a robust cow through integrative characteristics or properties. '*Longevity*' was mentioned by 50% of the farmers followed by '*transparency*' (36%) and '*ability to adapt*' (33%). Transparency means that the animal is totally transparent within the system. This last expression (*The better females are those you never hear about*) was also reported by Brochard *et al.* (2016) in a survey concerning all the ruminant females.

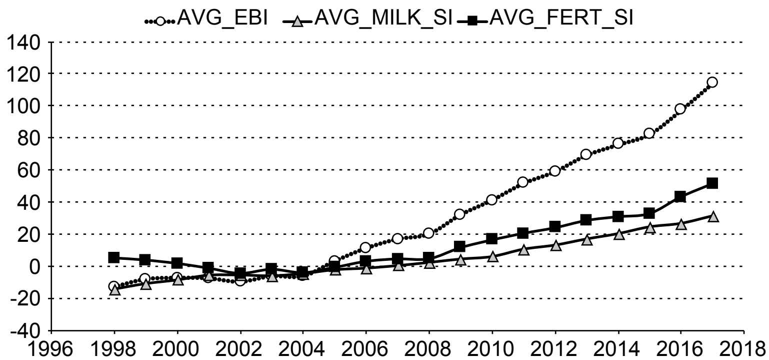

Figure 5. Rate of genetic gain in Economic Breeding Index (EBI), Milk sub-index (MILK_SI), Fertility sub-index (FERT-SI); € per lactation) for dairy females born in Ireland between 1996 and 2017 (source: A. Cromie, Irish Cattle Breeding Federation, personal communication).

Conclusion

For [semi] intensive pasture-based systems, robustness can be defined under three broad characteristics: (1) match high milk or growth performance to high forage intake capacity, (2) ensure high fertility (cattle) and prolificacy (sheep) and the delivery of offspring without assistance, and (3) remain healthy. These three main objectives challenge breeding and genetic research to define and be able to evaluate the best parameters to select future generations of ruminant livestock. Multi-trait selection is definitely more complicated than single trait selection as has been the focus in the past. It must be cognisant of sustainability within future ruminant feeding systems.

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Grazing by free-ranging red deer: effective management for semi-natural grassland conservation?

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Abstract

How to maintain open habitats is a critical question for nature conservation, especially if the area of concern is large and difficult to access. Central to preventing natural succession and maintaining protected grasslands is the removal of biomass, which can be successfully achieved by livestock grazing. The effectiveness of grazing by wild-living autochthonous mega-herbivores has not yet been evaluated. On a military training area (Grafenwoehr, Bavaria, Germany) with high density of red deer (*Cervus elaphus*), we surveyed grassland productivity, forage quality and forage removal by red deer in burnt (B), mown (M) and untreated (U) grasslands (five replicates per treatment) on five dates per year in 2015 and 2016. Forage removal by red deer was 31.5% (B), 42.2% (M) and 44.3% (U) of the average annual net productivity (B: 385 g m^{-2}; M: 486 g m^{-2}; U: 410 g m^{-2}). Forage removal rates peaked at 1.5 to 1.9 g m^{-2} d^{-1} between April and June. Forage quality was improved in mown grasslands after mowing. Red deer grazing could reach biomass removal rates comparable to those in extensive livestock grazing systems. Considering red deer as a grazing species could thus expand the established management options for large-scale grassland conservation.

Keywords: grazing, wildlife management, NATURA 2000, mowing, fire, forage quality

Introduction

The decline of traditional extensive land use systems in favour of agricultural intensification (or abandonment) and the accompanying loss of semi-natural open habitats during the last century is still a challenge to nature conservation in Europe. Most alarming is that only 5.2% of the grassland habitats protected under the EU Habitats Directive are in a favourable conservation status (European Environment Agency, 2015). Extensive livestock grazing has become a valuable management tool for the preservation of semi-natural grasslands (Gilhaus *et al.*, 2013), but is difficult to implement (e.g. with regard to fencing (Bunzel-Drüke *et al.*, 2008)), where the area is large or access is restricted. This is especially true for military training areas, which often have high nature conservation value (Warren *et al.*, 2007), but bring along even more difficulties for conservation management, e.g. unexploded ordnance or animal welfare concerns. In this context, wild herbivores could be an alternative management option for grassland conservation. We, therefore, assessed which proportion of the aboveground net primary productivity (ANPP) free-ranging red deer (*Cervus elaphus*) can remove/consume in semi-natural grasslands. We hypothesised that additional management (burning, mowing) improves forage quality and affects red deer forage removal.

Materials and methods

The study was conducted on the US Army Garrison Grafenwoehr military training area (GTA) in Bavaria, Germany (49° 40' 56'' N, 11° 47' 20'' E; c. 230 km^2). Out of the c. 9,000 ha of open habitats within GTA, 340 ha are designated as the NATURA 2000 habitat type 6510, lowland hay meadows. Wildlife, mostly red deer, is abundant on GTA.

We used movable exclusion cages to assess grassland productivity and forage removal by red deer on five lowland hay meadow sites in 2015 and 2016. Each of the five sampling sites (c. 1 ha) comprised three treatments (225 m^2 plot size): burnt (B), mown (M) and untreated (U) grassland. The respective plots were burnt in March/April and mown in July. We translocated the exclusion cages and collected hand-pluck samples to analyse forage quality on five dates over each vegetation period. Crude protein (CP) and organic acid detergent fibre (exclusive of residual ash, oADF) in dried hand-plucked samples were determined by near-infrared spectroscopy. We analysed the main and interaction effects of year (2015, 2016), month (April, May, June, August, October) and management (B, M, U) on daily rates of productivity and forage removal as well as on CP and oADF by linear mixed effects models in R statistical software (v 3.3.1; R Core Team 2015). Treatment nested in sampling site was included as a random factor and variance structure functions were used if necessary to meet assumptions of heteroscedacity and normality of residuals. We reported results for the models most parsimonious in terms of second-order Akaike information criterion (AICc).

Results and discussion

Aboveground net primary productivity was lowest in the B treatment and highest in the M treatment (Table 1).

Averaged over both study years, absolute forage removal by red deer amounted to 31.5% (B), 42.2% (M) and 44.3% (U) of the ANPP, respectively. Considering mowing reduced the actual available forage mass by 237.8 g m^{-2} on average, red deer consumption accounted for 82.6% of the ANPP available to red deer in the M treatment, which supports our hypothesis. Forage removal rates peaked at 1.5 to 1.9 g m^{-2} d^{-1} between April and June (year × month: $F = 14.18$, $P < 0.001$) and, to some degree, mirrored the year-specific seasonal productivity patterns (Figure 1a; year × month: $F = 7.61$, $P < 0.001$). Opposing seasonal variations in CP and oADF indicated constantly decreasing forage quality starting from high quality spring forage (Figure 1b and 1c). As hypothesised, the M treatment provided considerably higher forage quality in the late season after mowing (treatment × month: $F = 27.76$, $P < 0.001$ (CP); $F = 39.35$, $P < 0.001$ (oADF)). Year × month interactions were significant but minor ($F = 7.50$, $P < 0.001$ (CP); $F = 18.39$, $P < 0.001$ (oADF)).

Annual forage removal averaged over all treatments equalled 1,692 kg $ha^{-1}y^{-1}$. Based on a standard animal unit (AU) requiring 8.8 kg dry matter d^{-1} at maintenance level (Allen *et al.*, 2011), this can be translated to a theoretical stocking rate of 0.53 AU ha^{-1} y^{-1}. Given that a stocking rate of 0.5 AU ha^{-1} y^{-1} is recommended for neutral grasslands in extensive systems (Crofts and Jefferson, 1999), this rough estimation indicates that red deer forage removal in semi-natural grasslands could be relevant to nature conservation. Moreover, red deer grazing appeared to be influenced by forage quality patterns resulting in a high forage removal in spring and early summer, which is an important aim of grassland conservation in order to prevent the accumulation of unpalatable dead plant material (Crofts and Jefferson, 1999).

Table 1. Mean and 95% confidence interval (CI) of aboveground net primary productivity (ANPP) and red deer forage removal (g m^{-2}) in burnt (B), mown (M) and untreated (U) grasslands (n = 5).

Treatment	ANPP				Forage removal			
	2015		2016		2015		2016	
	Mean	CI	Mean	CI	Mean	CI	Mean	CI
B	412.3	92.8	357.5	17.4	160.7	77.8	82.0	35.6
M	495.4	81.5	476.3	45.4	185.2	54.0	224.5	91.0
U	396.3	114.0	422.9	45.0	184.2	91.1	178.8	41.1

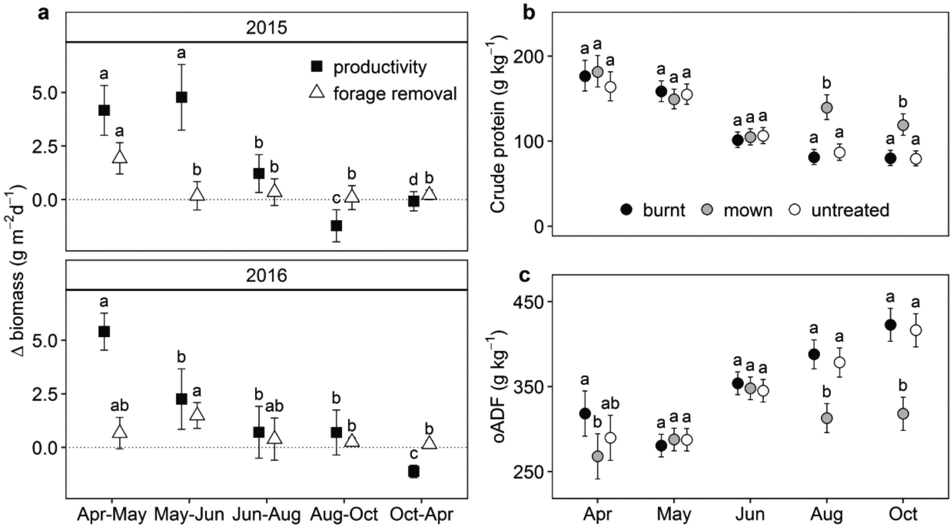

Figure 1. Daily rates of aboveground net primary productivity (DM) and red deer forage removal averaged over all treatments measured for five growth periods in 2015 and 2016 (a). Crude protein (b) and oADF (c) for the different treatments were averaged over both study years. Symbols represent least square means and lines indicate the 95% confidence interval.

Conclusion

We provided evidence that free-ranging red deer, given a sufficient population density, can be effective grazers in semi-natural grasslands and, hence, could present an appropriate management option for target areas where conventional conservation measures are difficult to implement (e.g. regarding area size or accessibility). Enhancing late season forage quality by mowing appeared to increase grassland attractiveness to red deer and could, therefore, possibly be used to direct red deer foraging activity in specific areas.

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Perspectives on the use of animal as replicate in grazing experiments

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Abstract

The policy of some animal science journals to reject animal grazing papers where the individual rather than the herd was used as the basis of analysis has caused considerable difficulties for scientists studying grazing systems. This paper proposes a strategy, based on institutional cooperation and detailed research of the basis for these policies, and to inform a debate on how these policies should be reviewed.

Keywords: grazing experiments, experimental unit, review of journal policies, holistic vs reductionist

Introduction

Animal science journals have adopted strict policies of rejecting manuscripts where the basic experimental unit for treatments is not replicated. Aspects of these policies are reflected upon as they impact on grazing experiments. In this paper, a number of key points of the scientific and statistical basis for the policy decisions are explored. A strategy for concerned research workers to develop a science-based case for a review of journal policies is proposed.

Here, the focus is on system grazing experiments in which a number of herds of animals are subjected to different treatments and the analysis relies on the variation between animals within a herd as the basis for inference on the treatments. The validity of results from such experiments has been questioned based on (1) animal behavioral studies (e.g. Rook and co-workers (1991, 1994, 1997 and 1999)) and (2) statistical issues (e.g. St-Pierre (2007), Bello *et al.* (2016)). The above behavioural work is seriously flawed statistically (e.g. incorrect definition of experimental unit) and in how it has been interpreted (confusion on linking synchronous behaviour to causality) to produce a strong criticism of grazing experiments as described. While accepting that there are statistical difficulties with such grazing experiments, the critique may be somewhat narrow and methods of dealing with the arguments could be explored (e.g. Jason and Elston (2002)).

These experiments lie at the intersection of important scientific, statistical, environmental and agronomic axes; they are an important link in the chain between detailed component science and practical agriculture. They should be given particular detailed consideration before they are discarded as not being 'real science'. They are carried out in a complex experimental space full of difficulties not faced by other animal studies. The issues of such experiments should be considered within a holistic vs reductionist framework.

Any argument to promote a review of the role of these experiments must be based on science and supported by top level peer-reviewed research. A strategy is proposed for researchers in this area based on (A) institutional and (B) research initiatives.

Strategy: The basis of journal decisions should be examined in a two-pronged strategy involving inter-institutional collaboration and a research programme to analyse issues around grazing research and journal policies. This could lead to improved research and provide a basis for a review of journal policies.

A. The institutional arm (which could be initiated at this EGF meeting) would:
- Establish an international network of interested scientists and institutions to collaborate on this project (e.g. build on EGF Grazing Working Group).

- Detail the editorial policies of journals and the reasoning behind their introduction.
- Quantify the expected impacts of the journal policies on system grazing experiments.
- Explore whether there are related issues in grazing experiments and similar issues with other areas of experimentation.
- Seek review of journal policies (eventually).
- Consider the modalities of inter-institutional research projects in grazing research.

B. The research arm would examine the basis of journal policies and lead to several scientific papers and could form the basis for a PhD programme. Three themes are important:
   1. Critique of animal behavioural studies.
   2. Critique of statistical arguments and exploration of alternatives.
   3. Evaluation of criteria for grazing studies.

Ad 1. Studies conducted by Rook and co-workers (1991, 1994, 1997 and 1999) explored 'behaviour synchronisation (BS)', the extent to which animals in a group engage in the same activity at the same time, and 'social facilitation (SF)', whether animal behaviour affects the behaviour of others in the group. These studies claim that animals in a grazing group are not independent and consequently, that individual animals should not be used as independent replicates in grazing experiments. This behavioural work may be seriously flawed both statistically and in how it is interpreted. The following are some of the relevant research questions:

- How to separate BS and SF in analysis. Analyse the role of external factors in BS and whether BS undermines the use of animals as replicates (Delagarde, 2010) for all experimental responses.
- Does BS alone produce dependence between animals?
- Is the definition of synchronous behaviour limited?
- Are statistical methods used in Rook *et al.* (all papers) valid?
- Do Rook *et al.* provide clear evidence for social facilitation?
- Suggest methods to show existence of social facilitation.
- Suggest alternative statistical methods.

Ad 2. Broaden discussion of St-Pierre (2007) and Bello *et al.* (2016) that it is not statistically valid to use individual animals as replicates in unreplicated animal group experiments.

- Explore ideas in Jason and Elston (2002; Peterson and Lucas, 1960).
- Review ideas on competition (Conniffe, 1976; St-Pierre, 2007) and selection as processes affecting variation within groups.
- A review and combined analysis of data from grazing experiments with replicated herds worldwide would provide crucial information in discussing these issues. Review role of multi-site inference and combined analysis – requirements for inclusion in a meta-analysis.

Ad 3. Broader evaluation for the criteria in grazing studies? Critique of biological and practical issues in relation to the proposal to only accept 'systems grazing experiments' with replicated herds. The critique will include:

- Information and the strength of inference in science: from designed lab experiment to field evaluation, but see Hurlbert (1984). Is some information better than none?
- How are the scientific question(s), the execution of the experiment and practical application changed by experimenting with replicated smaller sized herds?
- A broader scientific/technological impact may be that fewer system experiments will be done. Explore the consequences, both scientific and practical.
- Role of multi-site studies in mitigating some of these problems.
- Discussion of other experiments with similar constraints.

Conclusion

The imposition of a policy by some animal science journals to reject papers involving animal grazing where the individual, rather than the herd, was used as the basis of analysis has caused considerable difficulties of execution, relevance and application, for scientists studying grazing systems. So-called system experiments often incorporate grazing component research and are normally carried out with herds of a size that approaches commercial herd size. Replicating such herds is often difficult/impossible. It is long recognised that there are difficulties with such experiments but they have served as a very useful element in understanding complex systems and as an important link between research and field practice in commercial agriculture. Forcing researchers to adopt herd replication may result in either eliminating this step or working with a number of smaller herds that may risk seriously modifying the underlying scientific questions, inadequate experimental execution and limiting the value of the work to end users. The purpose of this initiative is to subject these decisions by journals to a more detailed scrutiny to ensure the best scientific outcome.

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Can we motivate dairy cows to increase their grass intake by feeding low protein supplements?

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Abstract

Literature shows that ruminants are able to balance their protein intake to meet their requirements. It would be interesting to know if this also applies to grazing dairy cattle. Our question was: Can we motivate grazing dairy cows to increase their intake of protein-rich grass by supplementing them with low protein concentrates? Sixty Holstein-Friesian dairy cows were allocated to two grazing systems (compartmented continuous grazing vs strip grazing), and two levels of protein supplementation Low (LP) vs High (HP). Treatment LP and HP received 5.5 kg DM concentrate cow^{-1} d^{-1}, which were different in rumen-degradable protein balance (OEB) (-57 vs +56 OEB kg DM^{-1}), but were equal in intestinal digestible protein (DVE) and net energy content. The cows grazed during the day and received 7 kg DM cow^{-1} d^{-1} maize silage indoors. During three periods, individual milk performance, total and grass DMI were measured. Grass DMI was not different between the treatments, total DMI was significantly lower in LP. This was due to a lower voluntary intake of maize silage. The reduced total DMI and nutrient intake explains the reduced milk and protein yield in LP. Feeding low protein concentrate is not a successful strategy to increase grass DMI.

Keywords: dairy cows, protein, grass intake

Introduction

Dairy cows given a free choice between silage based diets different in rumen degradable protein (RDP), selected a diet with sufficient RDP avoiding excess RDP diets (Tolkamp *et al*., 1998). Scott and Provenza (2000) found that lambs challenged by imbalances in dietary energy or protein, select foods and foraging locations to correct these imbalances. These findings raised the following questions: Does this also apply to grazing dairy cows and can we motivate dairy cows to increase their grass intake by feeding low protein supplements? The idea was that cows when kept indoors during the night and supplemented with maize silage and a concentrate low in RDP would be challenged with a (temporary) shortage of RDP. The cows can overcome this shortage of RDP through an increased intake of grass, which is usually high in RDP. If this mechanism works, this strategy could be implemented on the majority of dairy farms in the Netherlands, as most of the farmers practice a part-time grazing system with supplemental feeding indoors. In order to test the hypothesis, an experiment was carried out to study the effect of level of RDP supplementation on grass dry matter intake (GDMI) and milk production of dairy cows grazing during the day and housed during the night. In order to broaden the scope, this was done with two contrasting grazing systems which cover the most common grazing practices in the Netherlands.

Materials and methods

The experiment was carried out from 25 April to 27 October 2017 at Dairy Campus, the Netherlands (53°10 N, 5°45 E). Sixty Holstein-Friesian (HF) spring calving dairy cows were assigned to 15 blocks based on parity, days in milk, milk constituent yield, fat and protein corrected milk yield (FPCM) and body weight. The experiment involved two grazing systems (GS): comparted continuous grazing (CCG; an adapted set-stocking system in which the cows rotate on a daily basis between six compartments in one paddock) and strip grazing (SG) (see Holshof *et al.* (2018) for a detailed description of the grazing systems) and two levels of RDP (high; HP and low; LP) in a 2 × 2 factorial design, creating four experimental groups CCG-HP, CCG-LP, SG-HP and SG-LP. Within blocks, cows were randomly allocated to one of the four treatment groups. A difference in RDP between HP and LP was created by supplementing the cows with 5.5 kg DM d^{-1} of concentrate different in rumen-degradable protein balance (OEB, CVB (2012)) (-57 vs +56 g OEB kg DM^{-1}). The concentrates were equal in intestinal digestible protein (DVE CVB (2012); 117g kg DM^{-1}) and net energy content 7.8 MJ NEL kg DM^{-1}. The cows were milked at 05:00 h and 17:00 h and had access to pasture from 9:00 h to 16:00 h. During the remainder of the day the cows were indoors and were individually fed maize silage using transponder controlled weighing troughs (Insentec, Marknesse, NL). Intakes of concentrates and maize silage were recorded daily. Milk yields were recorded each milking; milk fat, protein and urea were recorded weekly during four consecutive milkings. During three experimental periods in June (Jn), July (Jl) and September (Sp), individual grass dry matter intake (GDMI) was determined using the *n*-alkane technique. During a 14-day dosing period, the cows were dosed twice daily with 0.45 kg of a concentrate containing 922 mg kg^{-1} C32 n-alkane, at each milking. From day seven to 14 of the alkane dosing period the herbage, maize silage and concentrates were sampled daily and pooled by treatment for the whole sampling period. During day seven to 14 of the dosing period, faecal samples were collected from each cow twice daily after each milking. The faeces samples were pooled into one sample for each cow. The concentrations of *n*-alkanes in feeds and faeces was analysed according to the procedures described by Abrahamse *et al.* (2009). On day six and seven, of the experimental period Jl and Sp, rumen fluid samples were collected by oesophageal sampling across four time points (4:00, 12:00, 15:00 and 21:00 h). The rumen fluid samples were analysed for the NH_3 concentration according to Riede *et al.* (2013). Concentrates, grass and maize silage were analysed for chemical composition and feeding value at Eurofins Agro (Wageningen, NL). A mixed model with repeated measurements was used to analyse the effect of the treatments on weekly mean milk performance, total DMI, GDMI, with protein treatment, grazing system and period as fixed effects and block and cow as random effects.

Results and discussion

The data on TDMI, GDMI, protein intake and milk performance are presented in Table 1. There was a significant P × RDP × GS interaction, indicating that GDMI changes differently during the grazing season. This can be explained by stage of lactation and the seasonal effects on grass allowance and composition. There was a significant RDP and GS effect on TDMI. Cows on the low RDP had larger refusals of maize silage than cows receiving a high RDP levels. This suggests that cows indeed seem to balance their RDP intake albeit, in this study, not through a higher intake of grass but due to a reduction of the voluntary intake of maize silage. Because the cows were supplemented with fixed amounts of maize silage, it is not possible to draw firm statistically substantiated conclusions. Supplementation with low RDP concentrate resulted in a reduced milk and milk constituent yield. Reduced milk yield can be explained by a reduced TMDI and hence, a reduced nutrient intake. Milk urea concentrations were lower than predicted on the basis of DVE and OEB balances (Schepers and Meijer, 1998). This was confirmed by low rumen NH_3 concentrations (2.63, 2.15, 1.84 and 1.35 mmol l^{-1} for CCG-HP, SG-HP, CCG-LP and SG-LP, respectively) indicating a shortage of RDP in LP and HP as well. The reason for this observation is unclear and requires further research.

Conclusion

We did not succeed in motivating cows to increase their grass intake by feeding low protein supplement grass.

Acknowledgements

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Table 1. Animal performance, predicted means of daily total dry matter intake (TDMI), grass dry matter intake, net energy, intestinal digestible protein (DVE), rumen degradable protein (RDP) balance (OEB), and milk and milk constituents yield with two grazing systems (GS) comparted continuous grazing (CCG) and strip grazing (SG) and two treatments with a high (HP) and low (LP) level of RDP across three experimental periods (P).

		CCG		SG		lsd	P	GS	RDP	GS×RDP	P×GS×RDP
		HP	LP	HP	LP						
GDMI	Ju	7.0	6.5	5.5	6.0	0.69	<0.001	0.654	0.508	0.437	<0.001
(kg.d^{-1})	Jl	4.1	4.1	4.6	4.9						
	Sp	2.9	3.3	3.5	3.8						
TDMI	Ju	19.9	19.0	19.5	18.8	1.08	<0.001	0.015	<0.001	0.945	0.555
(kg.d^{-1})	Jl	19.4	18.6	20.5	18.3						
	Sp	18.3	18.0	18.9	17.5						
NEL intake	Ju	151	141	142	135	7.14	<0.001	0.042	0.002	0.226	0.132
(MJ.d^{-1})	Jl	134	128	132	127						
	Sp	133	127	133	124						
DVE intake	Ju	1,782	1,599	1,648	1,566	78.4	<0.001	0.164	<0.001	0.451	0.136
(g.d^{-1})	Jl	1,606	1,513	1,614	1,550						
	Sp	1,550	1,505	1,565	1,486						
OEB intake	Ju	308	-419	213	-363	58.2	<0.001	0.348	<0.001	<0.001	0.002
(g.d^{-1})	Jl	233	-379	312	-274						
	Sp	194	-300	209	-311						
Milk yield	Ju	34.3	29.6	33.6	28.4	2.47	<0.001	0.740	<0.001	0.888	0.953
(kg.d^{-1})	Jl	30.7	25.7	30.9	25.8						
	Sp	29.0	25.0	29.3	25.4						
Fat	Ju	1.28	1.16	1.22	1.11	0.11	<0.001	0.44	<0.001	0.675	0.599
(g.d^{-1})	Jl	1.12	1.05	1.09	1.01						
	Sp	0.89	0.98	0.93	0.96						
Protein	Ju	1.19	1.04	1.14	0.98	0.08	<0.001	0.269	<0.001	0.226	0.826
(g.d^{-1})	Jl	1.08	0.94	1.05	0.91						
	Sp	0.96	0.91	0.97	0.90						
Urea	Ju	12	7	9	5	2.5	<0.001	0.122	<0.001	0.698	0.698
(mg.100 ml^{-1})	Jl	13	8	14	10						
	Sp	11	8	11	6						

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Feeding zero concentrate to dairy cows

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Abstract

Considering the future challenge of feeding the world's population, the distribution of potential foodstuffs to ruminants is under review. In Switzerland, efforts are under way to limit the share of concentrates used in annual rations, on organic farms, to 5%, and even zero concentrate feeding has been promoted. The aim of the study was to investigate the effects of two contrasting treatments for BioSuisse (federation of Swiss organic farmers) Standards, 0 kg and 750 kg concentrate per cow per lactation, on milk yield and composition, somatic cell count, body condition score and body weight of Holstein cow types of New Zealand or Swiss origin. The summer ration consisted of grazed herbage, the winter ration of hay. Cattle salt, minerals and drinking water were permanently available to all animals. Cows obtaining 750 kg concentrate produced more energy-corrected milk (6,244 vs 5,479 kg), fat, protein and lactose yields per standard lactation compared to cows receiving zero concentrate. Level of concentrate had no effect on fat, protein, lactose, urea concentrations and somatic cell counts (which serve as an indicator for udder health). Finally, cows showed similar body condition scores and body weights.

Keywords: concentrate, dairy cow, roughage, organic, Holstein

Introduction

Considering the future challenge of feeding the world's population, the distribution of potential foodstuffs to ruminants, particularly cereals, grain legumes and oilseeds, is under review. In Switzerland, efforts are under way to limit the share of concentrates used in annual rations, on organic farms, to 5%, and even zero concentrate feeding has been promoted. Ivemeyer *et al.* (2014) found only moderate effects of concentrate on milk yield and health characteristics, partly due to the small mean difference between the two treatments - only about 100 kg concentrate per cow per year. Also, Leiber *et al.* (2017) with a similar dataset as Ivemeyer *et al.* (2014), but with additional study years and a different evaluation approach, came to similar conclusions. The small reduction of concentrate tended to reduce the milk yield, but affected neither the milk composition, nor the fertility and the number of veterinary treatments. Unfortunately, the lack of impact could not be attributed to only the concentrate supplementation, as improvements in management over the study years were included. Furthermore, the maximum amount of offered concentrates was modest, about 6% of the year's ration. For a safe implementation of a strong limitation or a ban of concentrate supplements in dairy cow diets, knowledge about the effects of contrasting treatments under the same conditions over the whole lactation with different cow types is necessary. The aim of the study was to investigate the effects of two contrasting treatments for BioSuisse Standards, 0 kg and 750 kg concentrate per cow per lactation, on milk yield and composition, somatic cell count and body condition score (BCS) of two Holstein cow types.

Materials and methods

The three-year study is being undertaken at the organic farm 'Schulbauernhof Sorens' in Sorens, Switzerland and started in January 2015. In the first two years, a total of 50 Holstein cow pairs, 2/3 of Swiss origin (HCH) and 1/3 of New Zealand origin (HNZ), were included in the study. The average lactation number was 2.2, and the cows calved in the first half of each year. During the grazing period, the ration consisted of pasture herbage (n = 37, 178 crude protein (CP) ± 38 g standard deviation (SD), 232 acid detergent fiber (ADF) ± 30 g, and 6.1 MJ net energy lactation (NEL) ± 0.4 per kg dry matter (DM)), and during the winter it consisted of hay (n = 18, 102 CP ± 13 g, 303 ADF ± 22 g, and

5.0 MJ NEL ± 0.3 per kg DM). In the 750 kg treatment, the cows received, after an adaptation period, 4.5 kg (as offered) in the first 100 days in milk (DIM), then 2.5 kg until the 200th DIM and finally 1 kg of concentrate per day until the 300th DIM. The protein concentrate (n = 9: 423 CP ± 15 g, and 8.3 MJ NEL ± 0.2 per kg DM) was provided only during the winter feeding period, and the energy-rich concentrate (n = 13, 129 RP ± 12 g, and 8.1 MJ NEL ± 0.1 per kg DM) was provided during the whole year. Overall, the supplemented dairy cows consumed on average 746 kg of concentrate (as offered, ± 22 kg) divided into 653 kg (± 39 kg) of energy-rich concentrate and 93 kg (± 37 kg) of protein concentrate. On a scale from 1 to 5 (Edmonson *et al.*, 1989) the BCS for lactating cows was evaluated monthly.

A two-way analysis of variance (Systat 13, Systat Software, Chicago, USA) with the factors concentrate supplementation (0 and 750 kg) and cow type (Holstein cows of Swiss or New Zealand origin) was used for the statistical analysis of the variable sums or means for the standard lactation.

Results and discussion

The cows supplemented with 750 kg concentrate produced throughout the standard lactation (303 vs 304 d) more milk (6,028 vs 5,318 ± 967 kg, $P < 0.001$), energy-corrected milk (ECM, 6,244 vs 5,479 ± 936 kg, $P < 0.001$), fat (259 vs 230 ± 43 kg, $P < 0.001$), protein (203 vs 177 ± 30 kg, $P < 0.001$) and lactose (281 vs 247 ± 43 kg, $P < 0.001$) relative to the 0 kg treatment. There were no differences in terms of fat (43 vs 44 ± 4 g kg^{-1}, $P = 0.67$), protein (34 vs 34 ± 2 g kg^{-1}, $P = 0.24$), lactose (47 vs 47 ± 2 g kg^{-1}, $P = 0.70$) and urea concentrations (22 vs 23 ± 34 g dl^{-1}, $P = 0.12$). The somatic cell counts (5.0 vs 4.96 ± 0.3 log10 ml^{-1}, $P = 0.56$) did not differ between both treatments. No differences were seen for the averaged body condition scores (2.8 vs 2.7 ± 0.3, $P = 0.12$) and body weights (577 vs 564 ± 74 kg, $P = 0.39$) for 750 kg or 0 kg, respectively.

Between the two cow types, the following differences were found: HCH cows produced more milk (6,118 vs 5,229 ± 902 kg, $P < 0.001$) and ECM (6,066 vs 5,657 ± 873 kg, $P = 0.03$), but per body weight, HCH cows were less productive (10.0 vs 10.6 ± 1.1 kg ECM kg^{-1}, SD, $P = 0.006$) probably due to being heavier (608 vs 532 ± 69 kg, $P < 0.001$). The milk of HCH cows, compared to HNZ cows, exhibited lower contents of fat (41 vs 46 ± 4 g kg^{-1}, $P < 0.001$) and protein (32 vs 36 ± 2 g kg^{-1}, $P < 0.001$). Finally, HCH cows showed a lower BCS (2.6 vs 2.9 ± 0.3, $P < 0.001$) compared to HNZ cows. No interactions were found between the concentrate supplementation modes and the cow types.

The cows without concentrate supplementation produced a respectable amount of ECM (5,479 kg), even though the hay was of average quality with 5 MJ NEL and 102 g CP. Non-supplemented and supplemented HNZ cows showed lower milk yield per animal but increased ECM yield per kg of body weight compared to the HCH cows. For each additional kg of concentrate, the HCH cows produced 1.13 kg milk or 1.06 kg ECM, while the HNZ cows produced 0.77 kg milk and 0.99 kg ECM. These values are higher than those reported by Heublein *et al.* (2017), but they are in agreement with those from the review of Bargo *et al.* (2003). Horan *et al.* (2005) also found different milk production responses in relation to the Holstein cow types. They concluded that the optimum Holstein cow type would vary with the feeding system. The fact that the additional milk output per kg of additional concentrate is only around 1 kg has to do on one part with the substitution of forage by the concentrate and on the other part with the increased mobilisation of body reserves of non or less supplemented cows (Delaby *et al.*, 2003). In our study, the numerical differences in relation to body weight and BCS were not statistically significant. However, the averaged BCS of HCH cows over 305 DIM of 2.6 was fairly low and lower than the BCS of HNZ cows. Milk content and somatic cell counts, which are an indicator of udder health, were unaffected by the concentrate supplementation similar to the results of Leiber *et al.* (2017). In the case of larger supplemented amounts of concentrate, a decrease of the milk fat concentration and a slight increase of milk protein concentration has been reported by Heublein *et al.* (2017) and Delaby *et al.*

*(*2003). The milk of HNZ cows revealed far higher fat and protein contents. Leiber *et al.* (2017) reported no effect of concentrate reduction in low-input Swiss organic dairy farms on fertility. After completing the third study year, the fertility events will also be evaluated in this study.

Conclusion

The omission of concentrate supplementation resulted in reduced milk and ECM yields. No differences occurred in relation to milk fat, milk protein and urea concentration and there were no differences in somatic cell counts between supplemented and non-supplemented dairy cows. The averaged body weight and BCS were not significantly affected by the concentrate supplementation. Finally, the milk production response to concentrate supplementation and the BCS might give indications about the suitability of cow types in relation to the feeding systems.

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Effect of long-term grazing on dry matter biomass production and heifer performance

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Abstract

Stocking intensity is one of the main factors affecting grazing productivity. The effects of different grazing intensities on herbage production and live-weight gains of heifers were studied in an upland area in the northern part of the Czech Republic over 20 years (1998-2017). The sward was maintained at a target height of 5 and 10 cm under intensive (IG) and extensive (EG) grazing, respectively. Total biomass production in the grazing season was found to be higher under IG than under EG treatment. Heifers grazing the EG treatment had higher average daily weight gain in comparison to heifers grazing in IG. The particular year and month of vegetation season had the highest effect on seasonal daily weight gain of heifers, but there was no significant difference between breeds. Seasonal live-weight output per hectare under IG was approximately 1.5 times higher than EG treatment. However, if state subsidies are included, EG can be more profitable under the current Czech conditions than IG and satisfies both farmer and nature conservation objectives.

Keywords: grassland, cattle, herbage, live-weight gain

Introduction

In temperate grasslands, grazing intensities and animal preference have influence on the floristic composition and heterogeneity of vegetation, resulting in patchy structure of swards. Changes in agricultural management, such as intensive dairy production, has resulted in only a proportion of grassland being used while a vast area has been abandoned. The situation is exacerbated in more remote areas such as mountainous areas that have low productivity, where semi-natural grassland is common (Isselstein *et al.,* 2005). Extensification in terms of avoiding or minimising intensive application of fertilisers, as well as change in the frequency and timing of defoliation, can be beneficial. The main aim of this 20 year study in the Czech uplands was to investigate how intensive and extensive grazing affects forage yields and live-weight gains of heifers.

Materials and methods

The study was carried out at a 20 year long grazing experimental site (Oldřichov Grazing Experiment) located in the Jizera Mountains in the northern Czech Republic; in Oldřichov v Hájích village (420 m a.s.l.; average annual precipitation 803 mm; mean annual temperature 7.2 °C: Liberec meteorological station). Since 1998, the experimental site has been continuously stocked with young heifers each year from May to October /November. The experimental site was established in two completely randomised blocks. One block was formed using two paddocks with different grazing treatments and each experiment paddock was approximately 0.35 ha. Two treatments are applied: (1) extensive grazing (EG), where the stocking rate was adjusted to achieve a mean target sward surface height greater than 10 cm, and (2) intensive grazing (IG), in which the stocking rate was adjusted to achieve a mean target sward surface height of less than 5 cm. Further, stocking rate was changed throughout the grazing season by increasing or decreasing the area available for grazing by moving fences with a set number of stock per plot for IG or EG. The sward height in IG was maintained by four or five heifers and for EG by two or three heifers per paddock. The weight of heifers at the beginning of the experiment ranged from 150 - 250 kg with different types of breeds during the years 1998 - 2017. There was supplementary feeding of hay in the first 14 days of the grazing season. Data for dry matter (DM) production was collected every three weeks, from four movable cages 1 m × 1 m in size which were installed in each treatment paddock throughout the grazing seasons 2002 - 2017. Subsequently, the samples were weighted and dried for 48 h at 85 °C for DM yield. During each grazing season 1998 - 2017 (May - September), the heifers were weighed individually each month. Data were analysed using repeated measures of ANOVA to evaluate the effect of grazing on forage production and live weight gain of heifers during the growing seasons.

Results and discussion

There was a significant effect of treatment ($P < 0.001$), month ($P < 0.001$), year ($P < 0.001$), month and treatment interaction ($P = 0.020$) on biomass production but there was no effect of year and treatment interaction. Total biomass production in the grazing season was found to be higher under IG than EG and varied between 2.4 and 5.0 DM t ha^{-1} year^{-1} under IG, and between 2.3 and 4.7 DM t ha^{-1} year^{-1} under EG (Figure 1a). After the spring peak in May, the biomass production decreased regardless of the treatment during the vegetation season. Double peak (spring and summer) curves of biomass growth during the growing season were identified nine times in the 16 year experiment which makes it very unique compared to the more commonly found single peak curve in the spring in Czech uplands. The overall biomass production in both treatments consistently fluctuated from year to year and these fluctuations in biomass could be attributed to fluctuations in climatic parameters such as temperature and precipitation (Craine *et al.*, 2012).

There was a significant effect of treatment ($P < 0.001$), month ($P < 0.001$), year ($P < 0.001$), month and treatment interaction ($P = 0.041$), but no effect of year and treatment interaction on daily live-weight gain of heifers. The seasonal development of both treatments, with a peak in June, was similar and could be attributed to heifer's adaptation to pasture forage. Although the forage quality was higher in IG than EG treatment (Kassahun *et al.,* 2018), daily live-weight gain of heifers was higher under EG (803 g) than IG (703 g) treatment (Figure 1b). This could be due to the selective grazing of heifers assigned to the EG treatment, obtaining forage which reflected their need regardless of the quality. Is it also possible that EG treatment heifers could select forage of higher quality and their diet may not have differed that much compared to IG. A relatively higher year to year variability of daily live-weight gain of heifers from 424 to750 g under IG and from 620 to1020 g under EG was caused by: (1) different forage production and quality (Pavlů *et al.,* 2006); (2) selective grazing (Ludvíková *et al.*, 2015); and (3) grazing heifers of different live weight and ability to digest fresh forage at the beginning of the grazing season (Doležal and Gregoriadesova, 1996). The mean stocking rates over the grazing seasons were about 600 kg ha^{-1} for EG

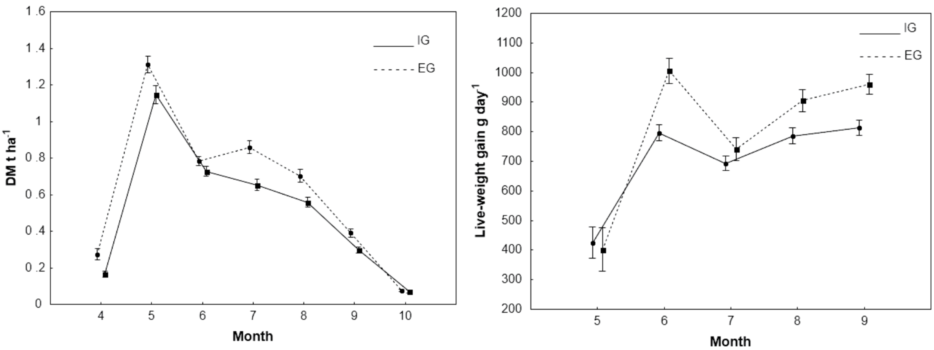

Figure 1. Seasonal development of a) on the left: biomass DM production (t ha^{-1}) in IG and EG treatment; b) on the right: live-weight gain of heifers (g day^{-1}) in IG and EG treatment. Numbers refer to the month of the year: 4-April, 5-May, 6-June, 7-July, 8-August, 9-September, 10-October. Standard errors are indicated by the vertical lines.

and about 1000 kg ha^{-1} for the IG treatment. As a result, although the stocking rate was almost double the total live output of heifers per hectare in the IG, treatment was about one and a half times higher than EG.

Conclusion

Considering the number of herbivores in the Czech Republic, findings suggest that EG is a better landscape management that can fulfil the livestock needs and mitigate temporary or permanent abandonment of grasslands.

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Comparing grass utilisation and herbage intake of elite New Zealand versus Irish ewes in the pre-weaning period

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Abstract

Pasture-based ruminant production systems are dependent upon the supply and utilisation of high quality swards to maximise animal performance within the grass based system. The aim of this study is to investigate the influence of high genetic merit ewes from two origins: New Zealand (NZ) and Ireland, on grass utilisation and herbage intake, while further comparing this to ewe milk yield during the pre-weaning period over two production years. Two groups of ewes representing elite NZ (n = 60) and elite Irish (n = 60) maternal genetics comprising of two main breeds (Texel and Suffolk) were assembled. Phenotypes collected from all ewes included live-weight and body condition score (BCS), while the milk production potential was estimated from a cohort of animals (n = 10 per genetic origin) on four occasions throughout lactation using the weigh-suckle-weigh method. Results indicate that irrespective of ewe genetic origin, grass utilisation and feed intake were similar ($P > 0.05$) in the pre-weaning period. Similarly, no difference in estimated milk yield of NZ versus Irish ewes were detected (2.01 ± 0.18 vs 1.92 ± 0.18 kg ewe^{-1}, respectively; $P > 0.05$). This study demonstrates the capability of high genetic merit ewes, irrespective of genetic origin, in maintaining BCS and achieving high levels of milk production in a grass based production system.

Keywords: genetics, sheep, grass intake, grass utilisation, lactation

Introduction

Profitable sheep enterprises require a ewe with good maternal characteristics whilst also optimising her lamb's growth potential in the pre-weaning period. Maternal lactational performance is one of the primary factors influencing lamb growth in the pre-weaning period (Morgan *et al.*, 2007). Consequently, to achieve high lamb growth rates, high ewe herbage intake must coincide with peak milk production at three to five weeks post-partum. Grass can supply up to 95% of the energy requirements of sheep (Davies and Penning, 1996) providing an opportunity for producers in temperate regions to operate in a more profitable manner through optimising herbage dry matter (DM) production and utilisation. Similar to Ireland, New Zealand sheep production enterprises are primarily pasture-based. Sheep maternal genetic indexes have been available for sheep farmers in New Zealand for over 20 years and large increases in genetic progress have been achieved within that period (Santos *et al.,* 2015). The aim of this study is to investigate the influence of genetic origin, elite New Zealand (NZ) and elite Irish ewes selected on their maternal ability, on grass utilisation, herbage intake and milk production in the pre-weaning period.

Materials and methods

The study consisted of two experimental groups representing high genetic merit ewes sourced based on the NZ (n = 60 ewes) or Irish (n = 60 ewes) maternal breeding objective. Two breeds (Texel and Suffolk) were represented within each group. The experiment was conducted over a two year period (2016 and 2017). Ewes had a mean lambing date of 8 March and were turned out to pasture, with lambs at foot, at approximately 48 h post-partum. Phenotypes collected on all ewes included live-weight and body condition score (BCS) at lambing and weaning, number of lambs reared and weaned per ewe. The daily milk yield of ten ewes per genetic origin was estimated twice per week, on weeks four and six of lactation using the weigh-suckle-weigh method (Benson *et al.*, 1999). Data on ewe live-weight, BCS and milk yield were analysed using a linear mixed model in PROC MIXED (SAS, 2012) with genetic origin (NZ or Irish), ewe breed (Texel or Suffolk) and year included as fixed effects in the model for all animal data. Days in milk and rearing litter size were included as fixed effects in the model for milk yield. In all models, ewe parity was included as the repeated effect and sire of the lamb was included as a random effect.

The elite NZ and Irish groups were managed separately in a rotational grazing system, with target post-grazing sward height (PGSH) of 3.5 cm for the first rotation and 4.0 cm for all subsequent rotations. Inorganic fertiliser nitrogen application rates were applied at a rate of 11 kg Nitrogen (N) ewe^{-1} year^{-1}. Nitrogen was applied prior to the first rotation and after grazing rotations two to six. Pre- and post-grazing compressed sward height (CSH) measurements were recorded on each paddock before and after grazing by taking 50 measurements across the diagonal of the paddock. The average paddock pre-grazing herbage mass (above target PGSH) was calculated according to the following formula: pre-grazing herbage mass (above PGSH) = ((Pre-grazing CSH (cm) - PGSH (cm)) × sward density); kg DM ha^{-1}. The proportion of herbage utilised to target PGSH and above 3.5 cm at each grazing was determined as herbage utilised = (herbage removed/herbage available (above target PGSH and 3.5 cm) at each grazing). A representative herbage sample was collected and dried at 90 °C for 16 h for DM determination. Data on pre-grazing herbage mass, pre- and post-grazing CSH, proportion of grass utilised and herbage intake were analysed using a linear mixed model in PROC MIXED (SAS, 2012) with genetic origin (NZ or Irish) season, rotation and year included as fixed effects.

Results and discussion

Ewe genetic origin had no effect on the quantity of grass consumed or the quantity of herbage utilised ($P > 0.05$; Table 1). This indicates that both elite groups have similar feed utilisation levels, provided optimum grassland management practices are maintained. The proportion of grass utilised to target PGSH in the present study supports previous findings where grass utilisation at varying stocking rates was investigated (Earle *et al.*, 2017).

There was no effect of genetic origin on ewe live-weight at lambing or weaning ($P > 0.05$), however, elite NZ ewes had a higher BCS at lambing when compared to elite Irish ewes ($P < 0.01$; Table 2). Interestingly, the results demonstrate that elite Irish ewes had a similar estimated milk yield to elite NZ ewes, 2.0l versus 1.92 ± 0.18 kg ewe^{-1}, respectively; while also gaining body condition throughout the 100 day period from lambing to weaning. Milk production levels reported in the current study are reflective of those previously observed for mid-season lactating Irish ewes (Campion *et al.*, 2017), thus verifying the adequacy of a grass based diet in achieving high levels of maternal performance throughout lactation.

Table 1. Effect of ewe genetic origin (elite New Zealand or elite Irish) on pre-weaning sward characteristics.

Pre-weaning sward characteristic	New Zealand	Irish	SEM	*P*-value
Herbage mass above target PGSH (kg DM ha^{-1})	1,309	1,236	62.69	NS
Pre-grazing herbage height (cm)	8.70	8.24	0.241	NS
Post-grazing herbage height (cm)	3.96	3.99	0.04	NS
Prop. utilised to target PGSH	0.99	0.98	1.41	NS
Prop. utilised to 3.5cm	0.89	0.88	1.02	NS
Herbage intake (kg DM ewe^{-1} day^{-1})	2.85	2.77	0.138	NS

Table 2. Effect of ewe genetic origin (elite New Zealand or elite Irish) on live-weight and body condition score (BCS) at two time-points, number of lambs born and number of lambs weaned per ewe.

	New Zealand	Irish	SEM	*P*-value
Ewe live-weight, kg				
Lambing	76	77	1.10	NS
Weaning	77	77	1.20	NS
Ewe BCS (1 - 5 scale)				
Lambing	3.30	3.13	0.07	0.003
Weaning	3.33	3.29	0.05	NS
No. lambs born and reared per ewe	1.58	1.46	0.168	NS
No. lambs weaned per ewe	1.55	1.43	0.094	NS

Conclusion

Results from this study demonstrate the capability of high genetic merit ewes, irrespective of genetic origin, in maintaining BCS and achieving high levels of milk production in a grass based production system.

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Accuracy of the ytterbium-faecal index method for estimating intake of pasture-fed dairy goats

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Abstract

There is no validated method for estimating pasture intake of dairy goats receiving concentrates and grazing on multispecies swards. The objective of this study was to determine the accuracy of a method based on estimates of faecal output (from ytterbium (Yb) oxide dilution), and of diet digestibility (from faecal N concentration). Four indoor experiments with six goats each were carried out between 2014 and 2016, comparing several feeding management factors: concentrate supplementation level, diet feeding level and pasture regrowth age. Actual daily intake, faecal output, *in vivo* diet digestibility, faecal N concentration and faecal recovery rate of Yb were determined individually over five days at the end of each period. Pasture intake was also estimated from faecal N and Yb concentrations. The relative mean prediction error between actual and estimated pasture intake was low (7%), with no line or mean biases, and a faecal Yb recovery close to 1.0. Random error came equally from the estimates of faecal output and of indigestibility. It is concluded that the Yb-faecal index method is accurate and suitable for estimating pasture intake of dairy goats grazing on multispecies swards whether or not supplemented with concentrate.

Keywords: goat, pasture, intake, methodology, ytterbium

Introduction

Grazing systems may be used to increase self-sufficiency and sustainability of dairy goat farms in the oceanic regions of France (Bossis, 2012). The lack of knowledge in relation to grazing dairy goat nutrition, however, precludes greater grazing utilisation. A reliable method for estimating daily pasture intake is needed for predicting variations of nutrient intake in grazing dairy goats under varying grazing and supplementation management practices. Two main generic methods for estimating individual pasture intake exist, one called the 'faecal output/digestibility' method (Penning, 2004) and the other the '*n*-alkanes' method (Mayes *et al.*, 1986). Grazing goats are generally offered multispecies swards, for which the *n*-alkanes method may be inaccurate due to the difficulty for estimating *n*-alkanes profile of the selected pasture. In the 'faecal output/digestibility' method', total intake (I) is calculated from the ratio between daily faecal output (F) and the indigestible fraction of the diet (1 - OMD), according to $I = F \times (1 / (1 - OMD))$. Pasture intake is then calculated by subtracting known supplement intake from total intake. Ytterbium (Yb) oxide may be considered as a good indigestible external marker for estimating faecal output (Pérez-Ramírez *et al.*, 2012). Recently, specific equations were developed for estimating diet OM digestibility from faecal N concentration in dairy goats fed on fresh forage (Charpentier *et al.*, 2017). The objective of this work was to determine the accuracy of the Yb-faecal index method for estimating forage intake of dairy goats fed indoors with conserved or fresh forage, across a large range of feeding strategies.

Materials and methods

Four trials were carried out in which forage distribution level (130 vs 80% of *ad libitum* intake level, determined before the start of each trial), concentrate supplementation level (no supplement vs 600 g day^{-1} of a pelleted concentrate), and age of regrowth of the pasture (from young and leafy pasture to aged and stemmy pasture) were the factors tested, with three or four treatments compared per trial. Trials were carried out at the INRA farm of Méjusseaume (Le Rheu, France), with six Alpine dairy goats per trial. Experimental designs were latin squares repeated two to three times, with three to four successive periods of 14 days, with measurements made the last week of each period. The basal forage fed was grass hay in trial 1 (Spring 2014), fresh multispecies pasture including grasses, clovers, chicory and dandelion in trial 2 (Autumn 2015) and fresh grass-based pasture in trials 3 and 4 (Spring 2016). Fresh pasture was cut once daily before feeding in four meals offered daily to goats. Goats were dry in trial 1, in late lactation and milked once a day in trial 2, and in mid-lactation and milked twice a day in trials 3 and 4. Goats were maintained in digestibility boxes allowing individual measurement of actual DM intake, faecal output and diet *in vivo* OM digestibility during five day total faecal collection periods (Charpentier *et al.*, 2017). Each goat received 0.13 g d^{-1} of Yb_2O_3, at each milking, mixed in a specific Yb-concentrate (15 g d^{-1}). Total and forage (hay or pasture) intake were estimated from faecal output assuming an Yb faecal recovery of 1.0, and from diet digestibility, estimated from faecal and diet CP concentrations according to specific goat predictive equations (Charpentier *et al.*, 2017). The ability of the Yb-faecal index method to accurately predict the actual values of forage and total intake, faecal output, as well as diet digestibility and indigestible fraction, was estimated on the entire database (n = 72 goat × period data), through the calculation of the mean prediction error (MPE) and its decomposition into three components: mean bias, line bias and random variation (Bibby and Toutenburg, 1977).

Results and discussion

In the entire database, actual forage intake, faecal output and diet OM digestibility ranged from 0.56 to 2.56 kg DM d^{-1}, from 0.18 to 0.60 kg OM d^{-1}, and from 0.636 to 0.832, respectively. The average and standard deviation of actual and estimated forage intake, total intake, faecal output, diet digestibility and diet indigestible fraction were very close, showing no overall bias of the method for estimating intake (Table 1).

Moreover, the regressions of estimated versus actual forage intake and their components (faecal output and diet digestibility) show high correlations (R^2 from 0.88 to 0.96) and low mean prediction errors (relative MPE from 0.02 to 0.07) (Table 1 and Figure 1). A relative MPE of only 0.07 clearly indicates a very accurate method. The similar relative MPE for faecal output and for the inverse of the diet indigestible fraction, both close to 7%, suggest that the error in estimating forage intake came equally from the two parts of the equation. Whatever the variable, the main source of error is random, with no overall mean or line bias (Table 1). For faecal output, this result should be directly related to the Yb faecal recovery rate that averaged 1.01 ± 0.069, meaning no bias and low variability of the faecal output estimation. This variability in Yb faecal recovery is similar to that already observed in dairy cows (Pérez-Ramírez *et al.*, 2012). The good ability of the faecal index equation to predict actual diet OM digestibility is due to the fact that the equation was calibrated from the same database, from data averaged per treatment and period (Charpentier and Delagarde, 2017). A lower accuracy of the intake prediction with other types

Table 1. Accuracy of the Yb-faecal index method for estimating actual DM intake (g d^{-1}), faecal OM output (g d^{-1}), diet OM digestibility (OMD), and the inverse of the indigestible fraction of the diet (1/(1 - OMD)) in dairy goats fed hay or fresh forage-based diets (n = 72).[1]

Variable	Actual	Estimated	R^2	MPE	MPEr	Percentage of MSPE		
						Mean	Line	Random
Forage DM intake	1,515 ± 548	1,518 ± 584	0.96	111	7.4	0	17	83
Total DM intake	1,823 ± 553	1,826 ± 580	0.96	111	6.1	0	11	89
Faecal OM output	378 ± 93	374 ± 90	0.92	27	7.1	2	0	98
OMD	0.762 ± 0.055	0.762 ± 0.052	0.89	0.018	2.4	0	0	100
1/(1 - OMD)	4.41 ± 0.91	4.37 ± 0.83	0.88	0.32	7.3	1	1	98

[1] MPE: mean prediction error, same unit as the corresponding variable; MPEr: relative MPE, in % of actual mean; MSPE: mean square prediction error (Bibby and Toutenburg, 1977).

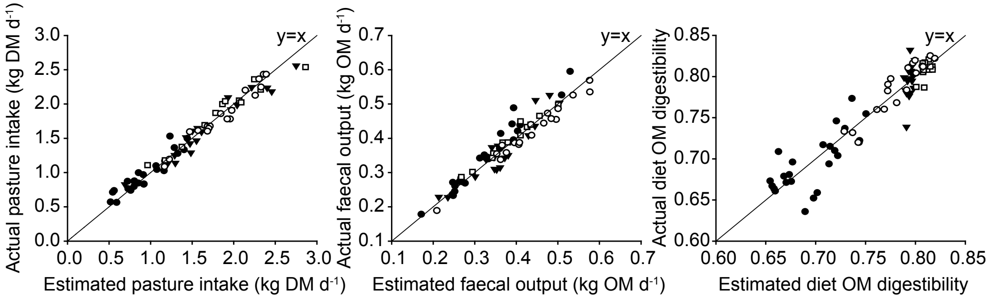

Figure 1. Relationship between actual and estimated values for (a) forage DM intake, (b) faecal output, and (c) 1/(1-OMD), when measured in dairy goats fed indoors on hay or fresh pasture-based diets (● trial 1, ▼ trial 2, □ trial 3, ○ trial 4) (n = 72).

of fresh forages or supplements could be expected but the digestibility predictive equations may always be improved from new calibration indoor experiments.

Conclusion

The complete faecal recovery of Yb independent of feeding regime and the suitability of the equation predicting diet OM digestibility make the Yb-faecal index method accurate for estimating pasture intake variations of dairy goats fed on forage-based diets. This method may be used for estimating intake of dairy goats grazing on multispecies swards and supplemented or not with concentrate.

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Influence of faba bean (*Vicia faba*, L.) silage on milk fatty acid profile of dairy cows

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Abstract

There are a growing number of stakeholders, especially organic product consumers, who are willing to pay a higher price for items made from sustainable systems which take into account soil-plant-animal-environment interactions. It is an established fact that dairy cows consuming forage represents the most sustainable and economic way to obtain milk with a healthier fatty acid (FA) profile. Different forage alternatives are being evaluated in order to minimise milk production costs while improving milk quality and producing high quality products with added value. A 3 × 3 Latin square trial was performed to evaluate the influence on the milk FA profile of including different proportions of faba bean silage in dairy cow´s ration (100% faba bean (FB); 50% faba bean + 50% Italian ryegrass (*Lolium multiflorum* Lam.) (FBIR); and 100% Italian ryegrass (IR)). The results showed that milk from cows offered FB presented a lower content of saturated FA (SFA) compared with milk from cows offered IR or FBIR (77.1 vs 82.1 and 80.8 g 100 g^{-1} SFA respectively, $P < 0.001$) and a higher content of unsaturated FA (UFA), especially oleic, linoleic and conjugated linoleic (CLA) acids, responsible for the improvement of milk fat quality.

Keywords: faba bean, Italian ryegrass, milk fatty acids, dairy cows

Introduction

The increasing interest of consumers around the areas of environment, animal welfare, origin of the product and method of animal production is reflected in a growing preference for food products from pasture-based production systems. According to Elgersma (2015), grazed grass is the most cost effective way of feeding dairy cows. In addition, diets based on pasture and grass silage can improve the nutritional quality of milk by shifting their FA composition toward less SFA and more polyunsatured fatty acids (PUFA), especially Ω3 FA (Dewhurst *et al.*, 2006). Kalac and Samkova (2010) reported that forage legumes show a higher transfer efficiency of PUFA to bovine milk fat in comparison with grasses. The inclusion of legume silages in dairy cow rations consequently allows improvement of the lipid profile of milk from the point of view of human health. This fact, together with the need to reduce costs, particularly for dietary protein and soil fertilizer, means that legume silages represent an important and interesting option for European farmers (Dewhurst *et al.*, 2003). Therefore, the aim of this study was to evaluate milk FA profile of dairy cows offered rations based on a legume silage, in this case faba bean, as alternative to Italian ryegrass silage.

Materials and methods

The trial was carried out at the SERIDA experimental farm (43°28'50" N, 5°26'27" W, 10 masl). Three silages made from faba bean monoculture (*Vicia faba* L., FB), Italian ryegrass monoculture (*Lolium multiflorum* Lam., IR), and faba bean-Italian ryegrass intercrop (FBIR) were included in three different total mixed rations (TMR). Details of these TMRs are set out in Baizán *et al.* (2017). Nine Holstein cows in the first half of lactation were used in a feeding experiment from October to December, 2015. At the beginning of the experiment, cows averaged 648 ± 59 kg of body weight and had an average daily milk yield of 29.6 ± 2.0 kg. The experimental design was a 3 × 3 Latin square with 3 rations and 3 cows for each ration and period. Each trial period included 14 days for diet adaptation and 7 days for data collection.

The offered TMRs were formulated as isonitrogenous (135 g crude protein kg^{-1} DM) and isoenergetic (9.3 MJ metabolizable energy kg^{-1} DM), were offered *ad libitum.* Cows were given 18 h daily access to temporary meadows, and were supplemented daily with 3 kg of concentrate (884 g kg^{-1} DM, 201 g crude protein kg^{-1} DM and 12.8 MJ kg^{-1} DM) as an energy source during milking. All animals had free access to clean drinking water. Cows were milked twice daily. The milk was sampled, during both daily milkings, twice a week on alternate days during the data collection. Milk FA analysis was completed as described by Hernández-Ortega *et al.* (2014). Results were compared by analysis of variance with a mixed model considering diet and period as fixed effects and cow as a random effect (R Core Team, 2016).

Results and discussion

Main milk FAs are shown in Table 1. The total SFA were lower in milk from cows eating rations with FB silage ($P < 0.001$) compared with those fed IR and FBIR.

The main SFA that contributed to the difference between treatments was the palmitic acid with values of 38.0, 41.2 and 42.4 g 100 g^{-1} FA for FB, IR and FBIR, respectively ($P < 0.05$). This acid is known to increase plasma cholesterol in humans (Yu *et al*., 1995). The FB treatment contained higher levels of PUFA, which are regarded as beneficial for human health, than IR and FBIR treatments, particularly linoleic acid (1.5 vs 1.3 and 1.0 g 100 g^{-1} FA for FB, IR and FBIR respectively, $P < 0.01$) and CLA (2.6 vs 1.7 and 1.8 g 100 g^{-1} FA for FB, IR and FBIR respectively, $P < 0.001$). Consequently, the unsaturated:saturated and polyunsaturated:saturated ratios were higher ($P < 0.001$) in FB treatment compared to IR and FBIR treatments. Other studies (Vanhatalo *et al*., 2007; Moorby *et al*., 2009) also reported the increasing proportion of monounsatured fatty acids (MUFA) and PUFA in milk at the expense of capric, lauric, myristic and palmitic acids when cows are fed with legume silage (red clover) *versus* timothy and fescue meadow or perennial ryegrass silage. There were no significant differences ($P < 0.05$) between treatments for α-linolenic acid (ALA), probably due to the biohydrogenation of this FA in the rumen. Despite this fact, FB showed a higher transfer efficiency of ALA to bovine milk fat in comparison with IR if we take into account that fresh IR forage contains 65.8 g 100 g^{-1} FA vs 53.1 and 35.0 for FBIR and FB respectively (Baizán *et al*., 2015). In addition to improving the milk FA profile, other studies conducted by Baizán *et al.* (2017) with the same silages, showed that the FB silage-based rations, do not affect the intake, milk production or milk chemical composition.

Table 1. Fatty acid composition (g 100 g^{-1} FA) of dairy milk from cows offered faba bean monoculture (FB), Italian ryegrass monoculture (IR), and FBIR intercrop silages.

	FB	IR	FBIR	rse	*P*-value
Palmitic acid	37.98^{a}	41.17^{ab}	42.41^{b}	4.978	*
Oleic acid	12.82	11.46	10.81	2.504	ns
Linoleic acid	1.47^{b}	$1.28a^{b}$	1.04^{a}	0.367	**
Conjugated linoleic acid	2.56^{b}	1.72^{a}	1.77^{a}	0.674	***
Linolenic acid	1.15	1.16	1.08	0.297	ns
Saturated fatty acids (SFA)	77.14^{a}	80.78^{b}	82.06^{b}	3.605	***
Unsaturated fatty acids (UFA)	22.86^{b}	19.21^{a}	17.93^{a}	3.603	***
Monounsaturated fatty acids (MUFA)	17.55^{b}	14.94^{a}	13.95^{a}	2.976	**
Polyunsaturated fatty acids (PUFA)	5.31^{b}	4.27^{a}	3.98^{a}	1.018	***
PUFA:SFA ratio	0.07^{b}	0.05^{a}	0.05^{a}	0.015	***
UFA:SFA ratio	0.30^{b}	0.24^{a}	0.22^{a}	0.051	***

[a,b] Values in the same row with different letters differ significantly; *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$.

Conclusion

Rations for dairy cows including FB silage modified milk FA profile. This legume led to a reduction in the palmitic acid content increasing MUFA and PUFA contents showing a healthier FA profile for consumers than FBIR and IR silages.

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Effect of pre-weaning nutrition on dairy heifer calf performance during the first season at pasture

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Abstract

Post-weaning, pasture-based systems can provide a cost effective method of rearing heifer calves. To improve efficiency of such systems, pre-weaning nutrition must promote good performance at pasture. The aim of this experiment was to investigate the effect of different milk replacer (MR) feeding regimes on performance at pasture. Immediately after birth calves were weighed and received colostrum at 8.5% of birth body weight (BW). Calves were then assigned to a treatment group, receiving, 6 litres per day of: (1) 26% crude protein (CP) MR at 125 g l^{-1}; (2) 26% CP MR at 200 g l^{-1}; (3) 20% CP MR at 125 g l^{-1}; or (4) 20% CP MR at 200 g l^{-1}. Live weight was recorded weekly pre-weaning and weaning occurred at 18% of mature BW. Post-weaning, calves were turned out to pasture, as single group, where live weight was recorded fortnightly. Grass was allocated *ad libitum*, with fresh grass allocated when calves had grazed to a post grazing residual of 4cm. Using a 26% CP MR at 200 g l^{-1} allowed earlier weaning to be achieved when compared with 20% CP MR at a rate of 125 g l^{-1}. No difference was observed in weight gain at pasture between the groups.

Keywords: heifer calves, milk replacer, pasture, weight gain

Introduction

Management of replacement heifers is an important component of dairy production systems and can influence the sustainability of an enterprise (Gabler *et al.*, 2000; Archbold *et al.*, 2012). Heifer rearing represents a significant expense, accounting for 15-20% of total farm variable costs (Stelwagen and Grieve, 1992; Heinrichs, 1993). The associated costs per heifer reared are in the region of €1550 (Shalloo *et al.*, 2014), with feed costs accounting for 60-65% of this figure (Gabler *et al.*, 2000). Grazed grass (perennial ryegrass) is an inexpensive, high quality feed (Finneran *et al.*, 2010) and could be used to reduce these costs. Maximising lifetime productivity centres on heifers being sufficiently grown (approx. 60% mature BW) to breed at 14-16 months of age, and produce their first calf at 23-25 months (Archbold *et al.*, 2012). This requires an average daily gain (ADG) of 0.6-0.7 kg in the first 24 months and particularly in the pre-weaning period as this can affect subsequent growth and first lactation milk yield (Carson *et al.*, 2002; Soberon *et al.*, 2012). Feeding milk replacer (MR) during the pre-weaning period is commonly practised. The crude protein (CP) content and concentration at which MR is provided can influence calf performance. Research has shown that feeding MR with high CP content (≥ 26%), at concentrations > 125 g l^{-1}, can increase pre-weaning performance levels (Diaz *et al.*, 2001; Hill *et al.*, 2010), however, there is limited information on subsequent performance at pasture. By improving performance in the first season at pasture, feed costs can be reduced, thereby, improving economic sustainability of dairy enterprises. The objective of this experiment was to investigate the effect of MR CP content and concentration on pre-weaning performance and post-weaning performance at pasture.

Materials and methods

The experiment was conducted in spring 2017 at the Teagasc Moorepark Research Farm, Fermoy, Co. Cork, Ireland. A randomised block design was applied, with a 2 × 2 factorial arrangement of treatments. Following birth, calves were removed from their dam, weighed (TruTest XR3000, Tru-test Limited, Auckland, New Zealand) and given colostrum at 8.5% of their birth body weight (BW). A total of 79 calves were used in the study; 47 Holstein Friesians (HF) and 32 HF × Jersey. Calves were balanced on breed, birth BW (32.72 (standard deviation (SD) ± 4.48) kg) and date of birth (7 February 2017 ± 8.39 d)) and assigned to one of the four following treatments: (1) 26% CP MR at 125 g l^{-1}; (2) 26% CP MR at 200 g l^{-1}; (3) 20% CP MR at 125 g l^{-1}; or (4) 20% CP MR at 200 g l^{-1}. Calves were housed throughout the pre-weaning period, in groups of fifteen, where maximum age difference within each group was fourteen days. Automatic feeding stations (Vario Smart Powder, TAP5–VS1–50: Förster-Technik GmbH, Engen, Germany) provided MR (6 litres d^{-1}; 3 × 2 litre feeds) according to treatment group. Weight recording was carried out weekly pre-weaning and calves had unrestricted access to coarse concentrates (18% CP, 10.4% crude fibre, 6.2% ash), hay and fresh, clean drinking water. Gradual weaning occurred, over a period of ten days, when calves reached 18% of mature BW, at which point they were given full-time access to pasture and offered 1 kg of supplementary concentrate feed per day. Grass was allocated *ad libitum*, with fresh grass allocated when calves had grazed to a post grazing residual of 4 cm. Post-weaning weight recording was carried out fortnightly. Statistical analysis was carried out using a mixed model (SAS Institute Inc., Cary, NC, Version 9.4). Average daily gains and weights at specific time points (e.g. 150 day weight) were adjusted for age and birth weights were categorised from 1 to 4: category 1 = 25-30 kg, category 2 = 30-35 kg, category 3 = 35-40 kg, category 4 = 40-45 kg. Treatment, breed and birth weight category were independent variables included in the model.

Results and discussion

There was no difference in ADG from birth to weaning (0.67 ± 0.02 kg d^{-1}) and weight at weaning (88.9 ± 0.93 kg) between treatments. There was a difference ($P < 0.05$) in the number of days required to reach weaning weight between 26% CP 200 g l^{-1} and 20% CP 125 g l^{-1} (76.5 v. 84.3 days) treatments. This would reduce pre-weaning expenses, such as labour and housing requirements and allow for early incorporation of grazed grass into the diet. Post-weaning weights at pasture at 124, 150 and 170 days and ADG in the intermittent periods were not significantly different between treatments. This indicates that CP content and concentration of MR does not affect post-weaning performance in the first season at pasture, with good grassland management practises.

Table 1. Age and weight at weaning, pre-and post-weaning average daily gains, up to 170 days and bodyweight at 124, 150 and 170 days of age across the four experimental treatment groups.[1]

	26% CP 125 g l^{-1}	26% CP 200 g l^{-1}	20% CP 125 g l^{-1}	20% CP 200 g l^{-1}	SEM	*P*-value
Weaning age (days)	79.4^{ab}	76.5^{a}	84.3^{b}	79.7^{ab}	2.18	0.021
Weaning weight (kg)	89.9	88.3	89.3	87.8	1.53	0.605
Pre-weaning ADG	0.69	0.69	0.64	0.66	0.02	0.190
Weight 124 days	117	117	115	117	2.36	0.883
Weaning to day 124 ADG	0.63	0.64	0.63	0.66	0.05	0.959
Weight 150 days	135	133	128	130	3.69	0.358
124 to 150 day ADG	0.65	0.67	0.49	0.39	0.14	0.289
Weight 170 days	146	150	145	149	3.71	0.616
150 to 170 ADG	0.51	0.74	0.71	0.85	0.19	0.492
Birth to 170 day ADG	0.65	0.67	0.64	0.66	0.02	0.559
Weaning to 170 day ADG	0.61	0.65	0.64	0.66	0.03	0.519

[1] ADG = average daily gain; CP = crude protein.

Conclusion

Crude protein content and concentration of MR provided during the pre-weaning period can influence time taken to reach target weaning weight. Weight gain at pasture in the first season was not affected by pre-weaning MR management.

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Is selecting dairy cows for fat and protein contents an opportunity to maintain yearly compact-calving systems?

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Abstract

This study aimed to explore the effect of alternative selection strategies based on milk fat and protein contents instead of milk yield on reproduction of dairy cows. About 500 lactations were recorded, equally distributed among breeds (Holstein: HO or Normande: NO) and genetic groups with similar genetic merit for fat and protein yields and either high breeding values for milk yield (MILK) or fat and protein contents (CONT). Milk progesterone monitoring enabled the study of the reproductive performance. In both breeds, cows in CONT produced less milk (-763 kg in HO, -649 kg in NO), with higher fat content (+4.1 g kg^{-1} in HO and +3.9 g kg^{-1} in NO) and higher protein content (+1.6 g kg^{-1} in HO, +2.0 g kg^{-1} in NO) than cows in MILK. Cows in CONT had an earlier resumption of luteal activity than cows in MILK (-6 d in HO, -4 d in NO). There was no difference in ovulation detection rates between genetic groups. No difference in fertility performance was observed between genetic groups in NO. However, HO in CONT had a lower re-calving rate than in MILK (48 vs 55%). Selecting dairy cows for fat and protein contents may not be a good opportunity to improve reproduction.

Keywords: dairy cow, genetic merit, cyclicity, oestrus, fertility

Introduction

The consensus in the literature is that reproduction is impaired because dairy cows are investing most of their resources in milk production (Friggens *et al.*, 2010). The fat fraction of milk represents about 50% of the energy exported in milk, the protein fraction about 25% and the lactose fraction about 25%. Producing the same fat and protein yields (milk solids) through high contents would result in lower milk yield and lower lactose yield and thus result in less total energy exported in milk. Consequently, glucose would be more bioavailable for other functions such as reproduction, blood flow would diminish resulting in less hormones exported in milk and higher hepatic clearance (Wiltbank *et al.*, 2006). There is a lack of information concerning the reproductive performance of dairy cows selected on fat and protein contents compared to cows selected on milk yield, at comparable milk solids yield. The present study aimed to explore the effect of genetic merit for milk fat and protein contents compared to milk yield on reproduction of dairy cows.

Materials and methods

Between 2006 and 2015, about 30 Holstein cows (HO) and 30 Normande cows (NO) were involved in a trial conducted at the INRA experimental farm of Le Pin-au-Haras (Normandy, France). Within breed, cows were classified according to their estimated breeding values into two genetic groups with similar estimated breeding values (EBV) for fat and protein yields (see details in Delaby *et al.*, 2010). Cows with high EBV for milk yield and low EBV for fat and protein contents were assigned to the milk group (MILK); those with low EBV for milk yield and high EBV for fat and protein contents were assigned to the content group (CONT). The EBV were expressed as a deviation from the reference population. The EBV for milk yields were +308 in MILK and -303 in CONT for HO and +290 in MILK and -264 in CONT for NO. For HO in MILK, EBV were -1.7 for fat content and -0.5 for protein content, compared to +1.9 and +0.5 respectively for HO in CONT. For NO in MILK, EBV were -1.9 for fat content and -0.9 for protein content, compared to +1.5 and +0.8 respectively for NO in CONT.

All cows were managed under a three-month compact calving pasture-based system. Oestrus behaviour were recorded five times a day using the standardized recording procedure of Kerbrat and Disenhaus (2004). The voluntary waiting period was set to 42 days *postpartum*. Cows were inseminated on spontaneous oestrus only. Pregnancy was diagnosed through ultrasonography examination.

Cows were milked twice a day, milk yield was recorded each time, fat and protein contents were estimated three times a week over two milkings. Morning milk samples were taken thrice a week to determine milk progesterone concentration for the monitoring of ovarian activity. Thresholds were estimated to distinguish ovulatory and luteal phases using the methodology of Cutullic *et al.* (2011). Commencement of luteal activity (CLA) was set as the time from calving to the first luteal phase. Based on CLA and cycle length, cyclicity profiles could be classified as normal or abnormal (CLA lower than 50d with regular cycles ranging from 20 to 25 days). Body condition score (BCS) was assessed once a month (0-5 scale, Bazin *et al.*, 1984).

Finally, 102 records on HO in MILK, 115 records on HO in CONT, 130 records on NO in MILK and 153 records for NO in CONT were analysed. Continuous variables (e.g. milk yield) were analysed through linear mixed models and dichotomous variables (e.g. ovulation detection) through generalised mixed models, with a random effect of the cow.

Results and discussion

To our knowledge, this is the first study comparing such genetic groups. In both breeds, cows in CONT produced less milk (-763 kg in HO, -649 kg in NO; Table 1), with higher fat content (+4.1 g kg^{-1} in HO and +3.9 g kg^{-1} in NO) and higher protein content (+1.6 g kg^{-1} in HO, +2.0 g kg^{-1} in NO) than cows in MILK. Milk solids production was similar in both genetic groups within breeds (+15 kg for cows in MILK compared to cows in CONT in both breeds). This was expected according to their genetic merit for production traits. Within each breed, there was no difference in BCS at calving between genetic groups. NO in the CONT mobilised less body reserves than those in the MILK (+0.25 BCS), this was not observed in HO. Cows in CONT had an earlier CLA than cows in MILK (-6 d in HO, -4 d in NO). There was no difference in ovulation detection rates between genetic groups. No difference in fertility performance was observed between genetic groups in NO. However, HO in CONT had a lower re-calving rate than in MILK (48 vs 55%). This was mostly explained by more non-fertilisation or early embryo mortality (33 vs 25%) and more late embryo mortality (14 vs 9%). Results comparing NZ and US HO strains are in line with our results (Horan *et al.*, 2005) although they had different genetic merit for milk solids yield.

Conclusion

To conclude, this study showed that, at similar genetic merit for milk solids, cows with high genetic merit for fat and protein content had earlier resumption of luteal activity, identical ovulation detection rate and re-calving rates than cows with high genetic merit for milk yield. Normande cows resumed ovarian activity on time. Holstein cows with high genetic merit for fat and protein contents produced a substantial amount of milk and had a degraded re-calving rate compared to those with high genetic merit for milk yield. Further studies are needed on the metabolic costs of milk production. Selecting on fat and protein contents instead of milk yield would not appear as a good strategy to improve reproduction at identical milk solids production.

Table 1. Adjusted productive and reproductive performance for Holstein (HO) and Normande (NO) cows, in milk (MILK) or content (CONT) genetic group.

	HO		NO		Significance levels[1]	
	MILK	CONT	MILK	CONT	B	B:G
Number of lactations	102	115	130	153		
Number of ovulations	237	343	376	462		
Production						
Total milk yield (kg)	7,609[d]	6,846[c]	5,765[b]	5,116[a]	***	***
Total milk solids (kg)	500[b]	484[b]	409[a]	393[a]	***	**
Average fat content (g kg^{-1})	36.0[a]	40.1[b]	39.4[b]	43.3[c]	***	***
Average protein content (g kg^{-1})	30.6[a]	32.2[b]	33.1[c]	35.1[d]	***	***
BCS at calving	3.00[a]	2.85[a]	3.40[b]	3.50[b]	***	ns
BCS at nadir	1.70[a]	1.70[a]	2.50[b]	2.75[c]	***	**
Reproduction						
CLA (d)	38[c]	32[b]	32[b]	28[a]	**	**
Normal cyclicity (%)	40	53	66	71	***	ns
Ovulation detection rate (%)	73	69	71	67	ns	ns
Non-fertilisation/early embryo mortality (%)[2]	25	33	22	25	*	ns
Late embryo mortality (%)[2]	9	14	5	8	*	ns
Re-calving rate (%)	55	49	73	68	***	ns

[1] Effects of breed (B) and genetic group within breed (B:G). Significance levels: *** $P \leq 0.001$; ** $P \leq 0.01$; * $P \leq 0.05$; + $P \leq 0.10$; ns $P > 0.10$.

[2] Combined outcomes of 1st and 2nd service.

[a,b,c,d] Distinguish adjusted means that are different between breeds and genetic groups.

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Compact-calving systems are better suited to dual-purpose than dairy cow breeds, particularly when nutrient supply is limited

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Abstract

This study aimed to explore adaptive trajectories of dairy and dual purpose breeds in contrasting grazing-based feeding systems (FS). About 500 lactations were recorded at the INRA farm of Le Pin-au-Haras, equally distributed among breeds (Holstein: HO or Normande: NO) and FS (High or Low). It was possible to study the different steps of the reproductive process by combining milk progesterone information (three times a week) with intensive oestrous behaviour recording and pregnancy diagnosis (ultrasonography). Holstein produced more milk (+2294 kg in the High FS, +1280 kg in the Low FS) and lost more body condition than NO. Cows in the Low FS produced less and lost more body condition than in the High FS. NO resumed ovarian activity earlier (-5 d) and showed a higher proportion of normal cyclicity patterns (+22%) than HO. There was no difference in ovulation detection rates between breeds or FS. The NO had a higher re-calving rate than HO (+19%). Feeding system was not associated with cyclicity and re-calving rate. By limiting their milk yield, NO did not experience a severe negative energy balance, unlike HO. This resulted in better reproductive performance for NO, suggestive of greater suitability to a compact calving system.

Keywords: dairy cow, breed, feeding system, reproduction, adaptive strategies

Introduction

In grass based systems, implementing a system with compact calving in winter (January to March) represents a good opportunity to optimise grass use. This relies on good reproductive performance. However, abnormal ovarian activity, low oestrus expression and low fertility are common in the modern day dairy cow (Walsh *et al.*, 2011). The consensus in the literature is that reproduction is impaired because dairy cows are investing most of their resources in milk production. This is mostly influenced by genetic characteristics and feeding strategies. The association between nutrition and reproductive performance is not straightforward but nutrition may affect both milk yield and body condition, known risk factors for impaired reproduction (Friggens *et al.*, 2010; Butler, 2014). This study aimed to characterise the robustness of dairy cows through examining breed by feeding system interactions. Our hypothesis is that the success of the reproductive process depends upon adaptive trajectories of milk production and body condition to periods of inadequate nutrition in dairy cows.

Materials and methods

Between 2006 and 2015, an experiment was conducted at the INRA experimental farm of Le Pin-au-Haras (Normandy, France). Dairy cows were equally distributed among two breeds and two grass-based feeding systems (FS). About 30 Holstein cows (HO) and 30 Normande cows (NO) were involved each year. Cows were randomly assigned to a High or Low FS and remained in the same FS until they were culled. In the High FS, diet was based on maize silage in winter and grazing with concentrates at pasture, this FS aimed to maximise milk yield while limiting body condition loss. In the Low FS, diet was based on grass silage in winter and grazing with no concentrate at pasture; this FS aimed to limit milk yield while inducing a large body condition loss.

All cows were managed under a three month compact calving system. Oestrus behaviour was recorded five times a day using the standardised recording procedure of Kerbrat and Disenhaus (2004). The voluntary waiting period was set to 42 days *postpartum*. Cows were inseminated on observed oestrus only. Pregnancy was diagnosed through ultrasonography examination.

Cows were milked twice a day, milk yield was recorded each time, fat and protein contents were estimated three times a week over two milkings. Morning milk samples are taken thrice a week to determine milk progesterone concentration for the monitoring of ovarian activity. Thresholds were estimated to distinguish ovulatory and luteal phases using the methodology of Cutullic *et al.* (2011). Commencement of luteal activity (CLA) was set as the time from calving to the first luteal phase. Based on CLA and cycle lengths, cyclicity profiles could be classified as normal or abnormal (CLA lower than 50 d with regular cycles ranging from 20 to 25 d). Body condition score (BCS) was assessed once a month (0 - 5 scale, Bazin *et al.*, 1984).

Overall, 101 records on HO in the High FS, 116 records on HO in the Low FS, 140 records on NO in the High FS and 143 records for NO in the Low FS were analysed. Continuous variables (e.g. milk yield) were analysed using linear mixed models and dichotomous variables (e.g. ovulation detection) through generalised mixed models, with cow included as a random effect.

Results and discussion

HO produced more milk than NO (+2,294 kg in the High FS, +1,280 kg in the Low FS; Table 1) with lower fat and protein contents. The HO cows had a lower BCS at calving than NO cows (-0.65 BCS in the High FS, -0.35 BCS in the Low FS), and lost more body condition (-1.00 BCS in the High FS, -0.80 BCS in the Low FS). This is consistent with the literature (Walsh *et al.*, 2008). As expected, cows in the High FS produced more milk (+2,495 kg for HO, +1,481 kg for NO) than cows in the Low FS. At calving, BCS was similar in both FS, and cows in the High FS lost less body condition to nadir than in the Low FS (+0.40 BCS for HO, +0.60 BCS for NO).

Table 1. Adjusted productive and reproductive performance for Holstein (HO) and Normande (NO) cows in the High or Low feeding system.

	HO		NO		Significance levels[1]		
	High	Low	High	Low	B	FS	B×FS
Number of lactations	101	116	140	143			
Number of ovulations	279	301	415	423			
Production							
Total milk yield (kg)	8,475[c]	5,980[b]	6,181[b]	4,700[a]	***	***	***
Average fat content (g kg^{-1})	37.4[a]	38.7[b]	40.8[b]	42.1[c]	***	***	NS
Average protein content (g kg^{-1})	31.9[b]	30.8[a]	34.9[d]	33.3[c]	***	***	*
BCS at calving	3.00[a]	2.90[a]	3.65[c]	3.25[b]	***	***	**
BCS at nadir	1.90[b]	1.50[a]	2.90[b]	2.30[c]	***	***	+
Reproduction							
CLA (d)	37[c]	33[bc]	32[ab]	28[a]	**	+	NS
Normal cyclicity (%)	47	47	64	73	***	NS	NS
Ovulation detection rate (%)	67	73	69	69	NS	NS	NS
Re-calving rate (%)	54	49	73	68	***	NS	NS

[1] Effects of breed (B), feeding system (FS) and their interaction (B × FS). Significance levels: *** $P \leq 0.001$; ** $P \leq 0.01$; * $P \leq 0.05$; + $P \leq 0.10$; NS $P > 0.10$.

[a,b,c,d] Distinguish adjusted means that are different between breeds and feeding systems.

The NO cows had a higher re-calving rate than HO (70 vs 52%), which is consistent with other studies (Dillon *et al.*, 2003). This final reproductive outcome is due to an earlier CLA (-5 d), a higher proportion of normal cyclicity pattern (68 vs 46%), and less pregnancy losses (6 vs 12%; data not shown) in NO than in HO. However, visual ovulation detection rate was excellent and similar in both breeds (70%). Reproductive performance of dairy cows was not affected by the FS. This is partly explained by compensative effects: milk yield could be a risk factor for impaired oestrus expression and late embryo mortality whereas body condition loss for impaired cyclicity and non-fertilisation or early embryo mortality (Cutullic *et al.*, 2012).

Conclusion

To conclude, this study showed that Normande cows had earlier resumption of luteal activity, identical ovulation detection rate and higher re-calving rates than Holstein cows. Nutritive supplementation did not support reproductive performance: Holstein cows prioritised milk production and Normande cows body reserves all the more with high nutritive inputs. The adaptive response of Normande probably limited the duration and intensity of negative energy balance and may have contributed to preserving their reproductive performance. With such a low re-calving rate, the use of high yielding Holstein cows does not appear to be a sustainable solution in pasture-based systems.

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Effect of plant extract based additive against coccidiosis development of lambs

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Abstract

Coccidiosis is a recurrent lamb disease provoking diarrhoea and reducing animal growth. A trial was conducted on grazing lambs from three to eight weeks old in order to evaluate the effect of a plant based feed additive on both performance and coccidiosis development. The trial was conducted on 2 × 8 lambs (Romney Marsh). The treated group received a daily supplementation, through individual gelatinous capsules, throughout the experiment. The control group were untreated (negative control). Live weight and blood samples were collected at D0, D21 and D35. Individual faecal samples were collected weekly for quantification and identification of *Eimeria* species. Two lambs per group were slaughtered on D21 and D35 for pathomorphological examination. High oocyst excretion at the beginning of the trial confirmed the presence of coccidiosis; on average, oocyst count was lower in the treated group ($P < 0.1$). No significant difference in growth performance was obtained (+ 3.2 and + 1.5 kg for the treated and the control group, respectively). Most of blood parameters indicated significant differences at D21 although white blood cells, iron and magnesium were higher for the treated group at D35.

Keywords: lambs, coccidiosis, plant extracts, serum biochemistry, haematology

Introduction

Coccidiosis, caused by *Eimeria* parasites, is an important disease in young ruminants. These protozoa develop in the intestinal epithelial cells creating lesions, intestinal inflammation and reduction of nutrient absorption. In spite of 80% of farms being affected by coccidiosis, 95% of coccidiosis cases stay subclinical and the growth reduction is estimated to be 12% (Gadwell *et al.*, 2005). When the *Eimeria* contamination is higher with the presence of highly pathogenic species (such as *E. ovinoïdalis* and *E. crandalis* in lambs), liquid diarrhoea appears, contributing to dehydration and performance loss. When the epithelium is highly damaged, it is possible to observe bloody diarrhoea with a higher risk of mortality (Gourrau *et al.*, 2011). The disease is difficult to eliminate due to resistance of oocysts in the environment and chronic excretion by adults. The disease is often provoked by a stress associated with an immune deficiency and challenging environment. Coccidiostats are often used to control the *Eimeria* development and maximise the growth of animals. Due to growing pressure by governments and consumers to reduce the use of antibiotics and coccidiostats in animal feed, new alternatives to prevent coccidiosis are now available. Plant extracts are commonly used in Europe to reduce the incidence of coccidiosis. The EMX product has been tested in calves, leading to a significant reduction in *Eimeria* development (Takagi *et al.*, 2006; Hardy *et al.*, 2006). The objective of this trial was to evaluate the efficacy of this natural based product in lambs with an evaluation of zootechnical parameters, oocyte excretion, blood analysis and intestinal lesions.

Material and method

The trial was performed on a private lamb farm in the Czech Republic, under the supervision of the University of Veterinary and Pharmaceutical Sciences of Brno. After deworming, two groups of eight lambs of Romney Marsh breed (Experimental and Control) were established at weaning (21 days of age) according to live weight and sex. Animals were housed in a paddock divided into two parts, during the summer period, with *ad libitum* access to hay and concentrate, in addition to fresh grass. The experimental group (EXP) received a plant based additive through daily gelatinous capsules throughout the experiment to ensure they consumed the recommended intake. The product is produced by Phytosynthese (France) and standardised in sapogenins, terpens and alkaloids. The Control group received empty capsules as a placebo. Live weights were recorded individually at D0, D21 and D35 of the trial; faecal samples were collected directly from the rectum of each animal at D0, D7, D14, D21, D28 and D35 to analyse coccidial excretion (McMaster technique) and to identify the *Eimeria* species. Blood samples were also collected from all lambs at D0, D21 and D35 from the *vena jugularis* into non-heparinized Hemos (Hemos H-02, Gama Group, Czech Republic) tubes to perform blood chemistry and haematology. Finally, two lambs per group were scarified at D21 and D35 to evaluate intestinal lesions. Lesion scores (from 0 to 3) were determined according to the signs of coccidial development in the intestinal mucosa. Results were analysed using the XLStat software with Anova analysis associated at the Newmann-Keuls test or a means comparison with Mann-Whitney test as necessary.

Results and discussion

The average daily gain was 99.7 vs 35.7 g d^{-1} $lamb^{-1}$ for the EXP and Control groups, respectively (Table 1). Due to the individual variability and low numbers of animals, significant differences were not found between the groups in growth performance results. From the first week of the trial, the EXP group showed, numerically, a lower excretion of *Eimeria* oocysts; for the average excretion between D7, D14, D21, D28 and D35, the EXP group tended to have a significant reduction in oocyst count (-39%; P = 0.07). In comparison, Takagi *et al.* (2006) and Hardy *et al.* (2006) obtained higher growth rates and reduced excretions in calf trials with this treatment. The *Eimeria* species identified during the trial in both the groups were: *E. ovinoidalis, E. ashata, E. faurei, E. parva, E. intricata.* Lesion scores are reported in Table 1; *Eimeria* lesions were observed in both groups and no significant differences were observed.

As shown in Table 2, creatin kinase (CK) and aspartate amino transferase (AST) which might be linked with intestinal lesions (Krueger *et al.,* 2014) was lower in the EXP group at D21 but no difference were observed at D35. Higher levels of vitamins A and E at D21 and iron (Fe) and magnesium (Mg) at D21 and D35 were observed in the EXP group.

Table 1. Growth and oocyst results (LW: live weight; DWG: daily weight gain; OPG: oocysts per gram; NS: non-significant) for the experimental (EXP) and control (Control) groups from day 0 (D0) to day 35 (D35).

		EXP	Control	Difference	*P*-value
LW D0 (kg)	n = 8	13.6 ± 1.2	13.8 ± 1.2	-1%	ns
LW D21 (kg)	n = 8	15.4 ± 1.1	14.3 ± 2.1	8%	ns
LW D35 (kg)	n = 6	16.8 ± 1.0	15.3 ± 3.1	10%	ns
DWG (g d^{-1})		99.7 ± 19	35.7 ± 73	179%	ns
OPG D0	n = 8	285,925	304,216	-6%	ns
OPG D7	n = 8	251,779	348,112	-28%	ns
OPG D14	n = 8	141,543	158,385	-11%	ns
OPG D21	n = 8	173,089	178,972	-3%	ns
OPG D28	n = 6	126,956	240,233	-47%	ns
OPG D35	n = 6	51,955	365,350	-86%	ns
OPG D7-35		156,756	255,379	-39%	0.07
Lesion Score D21	n = 2	2.5	2.5		ns
Lesion score D35	n = 2	0.5	2.5		ns

Table 2. Serum biochemistry and haematology (ALP: alkaline phosphatase; AST: aspartate amino transferase; CK: creatin kinase; Zn: zinc; Fe: iron; Mg: magnesium; HGB: haemoglobin; HCT: haematocrit; WBC: white blood cells) for the experimental (EXP) and control (Control) groups from day 0 (D0) to day 35 (D35).

Day	Treatment	ALP µkat l^{-1}	AST µkat l^{-1}	CK µkat l^{-1}	Zn µmol l^{-1}	Fe µmol l^{-1}	Mg mmol l^{-1}	Vit.A µmol l^{-1}	Vit.E µmol l^{-1}	HGB g l^{-1}	HCT %	WBC %
D0	EXP	10.44	2.23	5.96	11.64	30.62	1.00	1.29	3.26	110.4	32.5	8.50
	Control	15.23	2.36	6.78	13.77	26.16	1.04	1.08	2.42	113.9	35.4	8.76
	P-value	0.04	NS	NS	NS	0.09	NS	NS	NS	NS	NS	NS
D21	EXP	10.40	2.14	7.05	11.04	29.69	0.98	1.28	3.45	109.5	32.5	8.65
	Control	14.39	2.43	8.59	12.86	27.12	0.82	0.98	2.11	103.1	29.8	9.21
	P-value	0.03	0.04	0.09	0.013	NS	0.014	0.002	0.028	NS	0.07	NS
D35	EXP	3.63	2.46	7.23	11.70	19.6	0.99	1.57	1.32	101.2	31.4	11.68
	Control	3.77	2.16	9.02	9.57	15.0	0.90	1.37	1.14	98.3	32.7	9.23
	P-value	NS	NS	NS	0.008	0.08	0.06	NS	NS	NS	NS	0.04

Performed with 2 ×8 lambs, few parameters are statistically different between groups. The excretion and blood analysis results might be explained by the capacity of plant molecules to reduce the development of *Eimeria* and the intestinal cell invasion (Muthamilselvan *et al.,* 2016). Azeredo *et al.* (2014) demonstrated that some essential oils are able to block *in-vitro* differentiation of oocysts and to reduce their capacity of host cell penetration.

Conclusion

This trial evaluated the potential of natural plant extracts to reduce *Eimeria* development. Due to the low number of animals, no significant differences were obtained for live weight and lesion scores. The results of investigation indicate oocyte excretion tended to be reduced in the experimental group which might be associated with a better biochemistry status of some parameters. A larger study should be launched to confirm these results. Further investigations on the plant additives and their modes of action on *Eimeria* would be interesting to largely preconize these coccidiostatic alternatives in line with consumer demand.

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Effect of stocking rate and breed on dry matter intake and milk production efficiency

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Abstract

The objective of the experiment was to quantify the effect of stocking rate (SR) and breed on milk production, dry matter intake (DMI) and milk production efficiency across two consecutive grazing seasons (2014 - 2015) in an intensive spring calving system. Dry matter intake records were available for 68 Holstein-Friesian (HF) and 71 Jersey × Holstein-Friesian (J×HF) cows in each year of the experiment. Cows within each breed were randomly allocated to one of three SR treatments defined in terms of bodyweight (BW) per hectare (kg BW ha^{-1}): low (LSR; 1,200 kg BW ha^{-1}), medium (MSR; 1,400 kg BW ha^{-1}), and high (HSR; 1,600 kg BW ha^{-1}). Individual cow DMI was estimated three times per year: spring (March), summer (June) and autumn (September). The effect of SR, breed, season and their interactions were analysed using mixed models. Milk production, BW and milk production efficiency per cow decreased significantly as SR increased due to reduced herbage availability per cow and increased grazing severity. As a percentage of BW, J × HF cows had greater DMI, milk solids production and milk production efficiency.

Keywords: stocking rate, crossbreeding, dry matter intake, production efficiency

Introduction

Intensive grazing systems are dependent on achieving a balance between the competing objectives of managing swards to maximise grass growth, utilisation and quality, while maintaining high levels of individual cow intake. Within such systems, grazed grass is the cheapest feed source available to dairy cows (Finneran *et al.*, 2010). Producing a high proportion of milk from grazed grass maintains a low cost of production (Ramsbottom *et al.*, 2015). Within grass-based systems, dairy cows must be capable of achieving large intakes of high quality grass per unit of BW and efficiently converting the feed to high value milk solids (MS; kg fat + protein; Prendiville *et al.*, 2010). There is considerable evidence to suggest that Jersey (J) × Holstein-Friesian (HF) cows have a lower bodyweight (BW), increased intake per unit BW and greater efficiency of utilisation of feed for milk and tissue production compared with their HF contemporaries (Prendiville *et al.*, 2009). The objective of the present experiment was to investigate the effect of stocking rate (SR) and breed on milk production, dry matter intake (DMI) and milk production efficiency within a grass-based system. SR is defined in terms of kg BW per ha across two consecutive grazing seasons.

Materials and methods

The six experimental treatments consisted of three SR: low SR (LSR: 1,200 kg BW ha^{-1}), medium SR (MSR; 1,400 kg BW ha^{-1}), and high SR (HSR; 1,600 kg BW ha^{-1}) and two breeds: HF and J × HF. A total of 68 HF and 71 J × HF dairy cows were used in each year of the experiment (2014 - 2015). The genetic merit (Economic Breeding Index; EBI) was similar for each breed; €205 for HF cows and €198 for J × HF. The LSR treatment was designed to allow individual cows achieve high DMI and milk production, while the MSR and HSR measured milk production and grass utilisation per ha. Milk yield was recorded daily and milk constituents were recorded weekly. Cow BW and body condition score (BCS) were recorded fortnightly. Cow DMI was estimated using the *n*-alkane technique on three occasions during the grazing season, corresponding to spring (45 days in milk), summer (111 days in milk), and autumn (210 days in milk). The effect of SR, breed and their interaction were analysed using mixed models (PROC MIXED; SAS).

Results and discussion

Milk production, DMI, BW and BCS are presented in Table 1. The LSR achieved the greatest milk and MS yield (22.0 and 1.88 kg cow^{-1}, respectively), whereas milk and MS yield was similar for MSR (20.8 and 1.75 kg cow^{-1}, respectively) and HSR (20.9 and 1.74 kg cow^{-1}, respectively). Furthermore, LSR achieved the greatest grass DMI (15.3 kg DM cow^{-1}) and total DMI (17.0 kg DM cow^{-1}), whereas grass DMI and total DMI was similar for MSR (14.2 and 16.0 kg DM cow^{-1}, respectively) and HSR (13.9 and 15.6 kg DM cow^{-1}, respectively). Holstein-Friesian cows produced more milk, yet lower MS (21.9 and 1.77 kg cow^{-1} per day, respectively) compared with J × HF cows (20.5 and 1.81 kg cow^{-1} per day, respectively). Holstein-Friesian cows achieved a greater daily grass DMI (14.8 kg DM cow^{-1}) and total DMI (16.5 kg DM cow^{-1}) compared with their J × HF counterparts (14.2 and 15.9 kg DM cow^{-1}, respectively). Mean BW was 7.3% greater for HF (495 kg) than J × HF cows (459 kg), while BCS was similar across all treatments investigated.

Milk solids relative to total DMI is presented in Figure 1. Jersey × Holstein-Friesian cows produced more milk (115 g) compared with HF cows (108 g) relative to total DMI.

Table 1. Effect of stocking (SR) and breed (BR) on milk production, dry matter intake (DMI), bodyweight (BW) and body condition score (BCS).

	HF			J × HF			SEM	*P*-value		
	LSR	MSR	HSR	LSR	MSR	HSR		SR	BR	SR×BR
Milk production (kg cow^{-1} per d)	23.0	21.5	21.3	20.9	20.1	20.5	0.34	0.001	<0.001	0.171
Milk solids (kg cow^{-1} per d)	1.85	1.74	1.71	1.90	1.76	1.77	0.029	<0.001	0.087	0.798
Grass DMI (kg cow^{-1} per d)	15.7	14.4	14.1	14.8	14.0	13.7	0.20	<0.001	<0.001	0.350
Total DMI (kg cow^{-1} per d)	17.4	16.2	15.8	16.6	15.8	15.4	0.20	<0.001	<0.001	0.501
BW (kg)	510	492	483	467	466	443	6.5	<0.001	<0.001	0.161
BCS	2.99	2.97	2.97	2.97	2.96	2.96	0.016	0.737	0.409	0.886

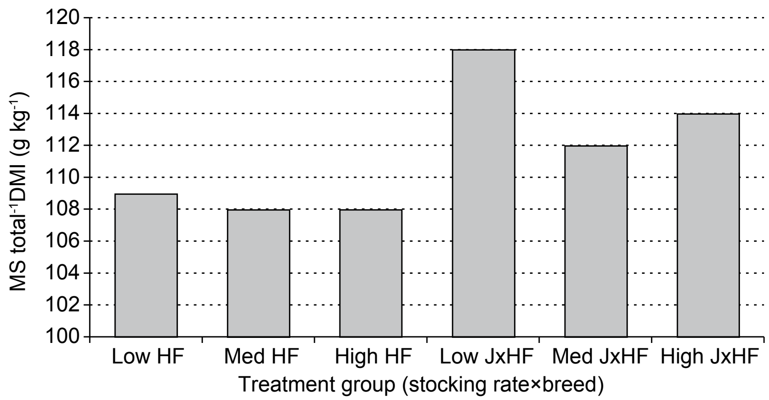

Figure 1. Milk production efficiency expressed in terms of kg of fat + protein (MS) produced relative to total dry matter intake (HF = Holstein-Friesian; J = Jersey; low = 1,200 kg BW ha^{-1}; medium = 1,400 kg BW ha^{-1}; high = 1,600 kg BW ha^{-1}).

Increasing SR was associated with a reduction in DMI per cow. The lower intake observed at higher SR was reflected in lower milk production per cow. The milk production efficiency of J × HF cows in the current analysis corroborates previous experiments (Prendiville *et al.*, 2009). Jersey × Holstein-Friesian cows achieved higher MS (+2.3% or 0.04 kg cow^{-1} day^{-1}), driven by greater fat and protein composition, despite a lower milk yield (-6.4% or 1.4 kg cow^{-1} day^{-1}) and lower feed intake (-3.6% or 0.6 kg DM cow^{-1} day^{-1}).

Conclusion

Milk production and total DMI reduced significantly as SR increased due to a reduction in herbage availability and DMI per cow. Additionally, the smaller size and associated lower DMI of crossbred cows appear to be compensated for by lower maintenance energy requirements. Consequently, MS yield per cow and MS produced as a percentage of BW were greater for J × HF cows than HF cows during the experiment. Although the opportunity to improve efficiency is limited, this experiment demonstrates the ability of J × HF cows to produce more milk from lower feed inputs, offering the potential to improve overall sustainability and profitability of dairy production systems.

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Biological performance of Holstein, Jersey, and Holstein × Jersey cows on Irish dairy farms

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Abstract

The objective of the study was to compare milk production and fertility performance of purebred Holstein, Friesian and Jersey, and their respective crosses on 40 Irish spring-calving dairy herds from 2008 to 2012, inclusive. A total of 24,279 lactations from 11,808 cows were available for analysis. Least square means for traits of interest were estimated for purebred and crossbred animals using linear mixed models. Milk yield was greatest for Holstein (5,217 kg), intermediate for Friesian (4,591 kg), and least for Jersey (4,230 kg), whereas milk constituents (fat and protein concentration) were greatest for Jersey (9.38%), intermediate for Friesian (7.91%), and least for Holstein (7.75%). Milk solids (MS) yield (fat kg + protein kg) was greater in crossbred cows compared with their parental purebred parents; greatest MS yield was observed in Holstein × Jersey first-cross, yielding 25 kg more MS than the parental purebred average. Holstein × Jersey cows calved younger as heifers and had a lower calving interval compared with their purebred parents.

Keywords: crossbreeding, heterosis, Jersey, Holstein-Friesian

Introduction

The biological and financial efficiency of predominantly grazing systems of milk production are dependent on a seasonal production model. The selection of appropriate cows for grazing systems is complicated by the importance of cows calving compactly at the beginning of the grass growing season. In order to achieve this, the national total merit breeding index (Economic Breeding Index; EBI) was developed to reflect the profit per lactation of progeny within Irish dairy systems (Berry *et al.*, 2015). The EBI includes 18 traits, where the relative emphasis on overall milk production and fertility are 33 and 35%, respectively (ICBF, 2014). Greater EBI is associated with increased farm profitability by virtue of increased productivity and improved reproductive performance compared with lower EBI counterparts (Ramsbottom *et al.*, 2012). Additionally, previous studies have demonstrated additional performance and financial efficiency benefits from crossbreeding by exploiting additive and non-additive genetic effects. Notwithstanding this, the practice of crossbreeding remains low in the national dairy herd in Ireland (~6%; Department of Agriculture, 2016). The objective of the study was to compare the biological performance of purebred Holstein, Friesian and Jersey cows, and their respective crosses using a large dataset of 40 dairy herds over a five year period.

Materials and methods

Milk production and fertility information from the Irish Cattle Breeding Federation database on 11,808 dairy cows from 40 spring-calving dairy herds that adopted crossbreeding between Holstein (> 87.5% Holstein), Friesian (> 87.5% Friesian) and Jersey (> 87.5% Jersey) breeds over a five year period (2008 - 2012, inclusive) were available. A spring-calving dairy herd was defined as a herd in which > 80% of the cows calved between 1 January and 31 May in each year of the study. Available data included milk production performance, date of birth, calving date, parity, service dates and pregnancy diagnosis. Milk production consisted of 305 day milk yield (kg) and milk solids (MS; fat kg + protein kg) yield. Age at first calving was defined as the age at which heifers calved for the first time and calving interval was defined as the number of days between consecutive calvings. Least square means for milk production and fertility traits of interest were estimated for purebred and crossbred animals using linear mixed models.

Results and discussion

Milk production and fertility performance are presented in Table 1. Milk yield was greatest for purebred Holstein cows, corresponding to 12 and 19% greater milk production than their purebred Friesian and Jersey contemporaries, respectively. Similarly, MS yield was greatest for Holstein cows, 9 kg (2%) greater than purebred Jersey cows and 43 kg (11%) greater than purebred Friesian cows. Holstein × Jersey first-cross cows produced more milk compared with the parental breed average, equating to 264 kg (heterosis = 5.6%) milk and 25 kg (heterosis = 6.5%) MS. Greater MS produced by Holstein × Jersey crossbred cows is demonstrated as non-additive in Figure 1. Purebred Friesian heifers calved 14 and 28 days younger than purebred Holstein and Jersey heifers, respectively. Holstein × Jersey first-cross cows calved 12 days younger as heifers compared with the parental purebred average, corresponding to 1.6% heterosis. Calving interval was shortest for purebred Friesian cows (376 days), intermediate for purebred Holstein (382 days), and longest for purebred Jersey cows (387 cows). Holstein × Jersey first-cross cows had an eight day shorter calving interval compared with the parental purebred average, corresponding to 2.4% heterosis.

Table 1. Biological performance of purebred Holstein, Friesian and Jersey cows and their respective crosses.

	Breed				
	Holstein	Friesian	Jersey	Holstein × Jersey	Friesian × Jersey
No of lactations	2,413	53	1,022	2,241	50
Milk yield (kg)	5,217[a]	4,591[b]	4,230[c]	4,988[d]	4,493[b]
MS yield (kg)	404[a]	361[b]	395[c]	425[d]	386[e]
Age at 1st calving (d)	744[a]	730[b]	762[c]	741[a]	743[a]
Calving Interval (d)	382[a]	376[b]	387[c]	377[b]	373[b]

[a-e]Within columns differing in superscript are different ($P < 0.05$).

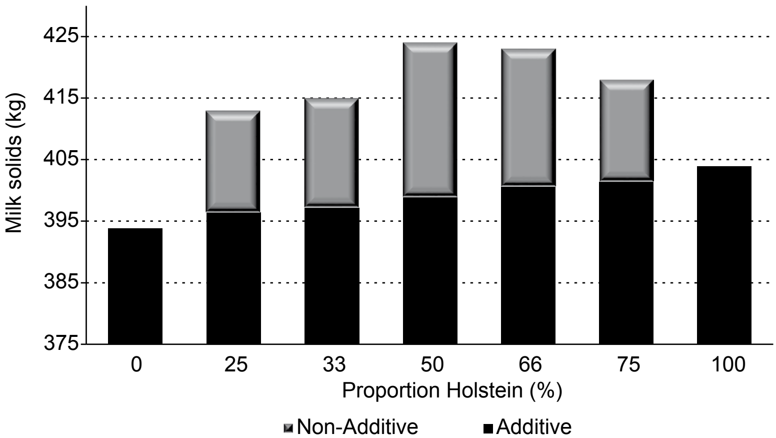

Figure 1. Additive and non-additive effect of crossbreeding between Holstein and Jersey on MS production.

Conclusion

The study illustrates the superior biological performance of crossbred cows relative to the average of parental purebreds within seasonal grass-based systems of milk production. The widespread adoption of crossbreeding offers the Irish dairy industry the opportunity to capitalise on heterosis for traits of economic importance and may result in greater profitability.

Acknowledgements

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Dairy cows eating grass produce milk with a higher proportion of fat-soluble antioxidants

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Abstract

The optimisation of milk production includes a rational use of forages, respect for the environment, and offers better quality to consumers. Pasture-based milk production is widely spread throughout the Atlantic Arc in order to maximise milk yield per hectare. Furthermore, it is well known that grazing cows produce milk with a healthier fatty acid profile. However, grass may provide other healthy components to milk. The aim of this study was to evaluate the effect of grass intake on fat-soluble antioxidant concentration in milk. For this, a 3 × 3 Latin square experiment was performed with 18 lactating cows in the second half of lactation. Experimental treatments consisted of grass silage, zero-grazing, both offered *ab libitum* in housing, or grazing for 24 hours. The results show that grazing cows had a higher dry matter intake and greater milk yield and higher concentration of protein and lactose in milk than housed cows. The milk from grazing cows had a greater proportion of xanthophylls and carotenes than cows eating grass silage, with the zero-grazing system having intermediate values. In conclusion, dairy cows eating fresh herbage produce milk characterised by a higher proportion of antioxidants than when eating grass silage.

Keywords: grass silage, zero-grazing, grazing, milk yield, antioxidants

Introduction

Milk has a great importance for humans because of its nutritional characteristics providing a high nutrient content in relation to its caloric content. Many studies show that milk produced from grazing systems has different characteristics in its components than milk produced from confinement systems (Kusche *et al.*, 2015). Fresh forages are an important natural source of antioxidants, vitamins and fatty acids in ruminant diets, and their concentrations in forage have an important relationship to the resultant composition and quality of milk and dairy products (Elgersma *et al.*, 2013). Higher levels of antioxidants (α-tocopherol, β-carotene and retinol) have been reported in milk from cows that consume fresh grass compared with diets rich in concentrate or silage (Havemose *et al.*, 2004; Agabriel *et al.*, 2007). Milk fat antioxidants have an important role in the maintenance of the pro-oxidant/antioxidant balance in the human body (Tijerina-Sáenz *et al.*, 2009). The objective of the present study was to examine the effectiveness of the delivery method of herbage: grazing, zero-grazing or silage, on milk performance and milk antioxidant profile.

Materials and methods

The trial was carried out following a 3 × 3 Latin square design, with three periods of 20 days, which included 14 days of adaptation and six days of sampling and measurements. Eighteen homogeneous Holstein dairy cows in the second half of lactation were selected and randomly distributed into three groups of six cows. Three treatments were tested: (1) *ad libitum* grass silage with housed cows; (2) *ad libitum* zero-grazing indoors; and (3) fulltime grazing. All treatments were supplemented daily with 6 kg of concentrate (875 g DM kg^{-1}, 214 g crude protein kg^{-1} DM and 12.6 MJ metabolizable energy kg^{-1} DM) offered during milking. Grazing and zero-grazing were carried out in paddocks with rotational management. During the experimental period, paddocks were assigned to the corresponding group of animals taking into account the available pre-grazing herbage mass. The grass silage offered was from the herbage harvested during the previous spring. Forage samples were taken daily to determine their dry matter content. A sample of the concentrate was taken at the beginning of the experimental period. After the adaptation period, the individual dry matter intakes and milk production were recorded daily. Herbage intakes on pasture were estimated using the animal performance method (Macoon *et al.,* 2003). Individual samples of milk were taken daily at each milking session (morning and afternoon) by an automatic sampler attached to the milking robot and mixed proportionally according to the milk produced. Milk samples were analysed by MilkoScan FT6000. Carotenoids and vitamins E and A present in the milk were determined according to the methodology proposed by Gentili *et al.* (2013). Dry matter intake, milk yield and milk composition were analysed by ANOVA using R statistical package (R Core Team, 2017) with type of management and period as fixed effects.

Results and discussion

Grazing cows had a higher dry matter intake than housed cows offered zero-grazed grass or grass silage (18.1 vs 14.1 and 15.2 kg day^{-1} respectively, $P < 0.001$). Milk yield was different among the experimental treatments, as was protein, lactose, solid non-fat and urea, with higher concentration in milk from grazing cows than housed cows (Table 1).

The content of fat-soluble antioxidants according to the type of feeding system is shown in Table 2. No effect of feeding method was observed in vitamins A and E in milk. Milk from grazing cows had a greater proportion of lutein than milk from cows offered grass silage ($P < 0.01$), with zero-grazing system showing intermediate values. However, there were no differences in carotenes concentration among treatments. Different studies reported that the content of β-carotene and fat-soluble vitamins were four times higher in the milk of grazing cows than in the milk of cows offered total mixed rations or high proportion of concentrate (Nozière *et al*., 2006; Butler *et al*., 2008), and its quality remained constant

Table 1. Milk yield and milk composition according to the feeding system.

	Grazing	Zero-grazing	Grass silage	RSD	*P*-value[1]
Milk (kg day^{-1})	23.4^a	18.1^b	14.0^c	3.57	***
Fat (g kg^{-1})	35.8	33.7	36.1	3.18	NS
Protein (g kg^{-1})	32.1^a	29.1^b	27.8^b	2.90	***
Lactose (g kg^{-1})	45.7^a	41.0^b	41.7^b	2.56	***
Solid non-fat (g kg^{-1})	83.9^a	77.8^b	76.3^b	3.79	***
Urea (mg kg^{-1})	281^a	200^b	215^b	40.3	***

[1] Statistical significance: *** $P < 0.001$

Table 2. Fat-soluble antioxidants composition (µg l^{-1} milk) according to the feeding system.

	Grazing	Zero-grazing	Grass silage	RSD	*P*-value[1]
Retinol	855	852	827	202.6	NS
α-tocopherol	1,189	962	1,068	237.5	NS
γ-tocopherol	17.8	19.9	23.3	3.50	NS
Lutein	21.9^a	15.5^b	9.1^c	3.19	**
Zeaxanthin	1.19	0.42	0.47	0.332	NS
β-cryptoxanthin	3.13	1.64	1.55	1.031	NS
All-trans-β-carotene	255	184	179	45.6	NS
9-cis-β-carotene	1.73	2.05	1.60	0.775	NS
13-cis-β-carotene	9.52	7.08	6.82	1.540	NS

[1] Statistical significance: ** $P < 0.01$.

throughout the study. However, our results did not show wide differences among treatments, perhaps because they were all based on very similar grasses.

Conclusion

Grazing dairy cows had higher milk production and higher concentration of protein, lactose, solid non-fat, urea and lutein. Vitamins A and E and carotene concentrations were similar across grass silage, zero-grazing or grazing treatments.

Acknowledgements

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Effect of stocking rate on pasture performance and lamb carcass output

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Abstract

The quantity and quality of pasture offered to grazing animals are key drivers of herbage utilisation and animal performance within grazing systems. This study investigated the effect of stocking rate (SR) on pasture parameters including herbage production, utilisation and nutritive value as well as effects on lamb average daily gain, lamb drafting pattern and lamb carcass output (kg ha^{-1}) from a grass based production system. The study was carried out over three production years. There were three SR treatments; low (LSR; 10 ewes ha^{-1}), medium (MSR; 12 ewes ha^{-1}), and high (HSR: 14 ewes ha^{-1}). As SR increased, the quantity of grass utilised ha^{-1} increased ($P < 0.001$). Stocking rate had no effect on herbage nutritive value ($P > 0.05$), however, a significant reduction in herbage energy level (UFL; Unite Fourrage Lait) occurred between rotation six and seven ($P < 0.05$). Lamb carcass output ha^{-1} increased as SR increased ($P < 0.001$) but the number of days taken to reach slaughter increased as SR increased ($P < 0.001$). This study demonstrates the potential to increase lamb carcass output from a grass based system through greater SR levels in combination with increased levels of grass production and utilisation.

Keywords: daily gain, carcass, herbage, socking rate

Introduction

Grass, either grazed or conserved, can supply up to 95% of the energy requirements of sheep (Davies and Penning, 1996), providing producers in temperate grazing regions with an ideal opportunity to maximise lamb carcass output from grass (Keady *et al.,* 2009). However, variable effects of increasing stocking rate (SR; ewes ha^{-1}) on sward productivity and animal performance have been reported within the literature. Findings from these studies have indicated increased SR levels to positively improve herbage DM production, utilization (Macdonald *et al.,* 2008; McCarthy *et al.,* 2012) and quality. However, others have shown that increased SR has a negative impact on pasture growth and animal performance (Orr and Newton, 1984). Therefore, the objective of this study was to investigate the effect of SR on herbage production, utilisation and quality, lamb performance and carcass output from a grass based production system.

Materials and methods

The study was conducted at the Sheep Research Demonstration farm, Teagasc, Animal and Grassland Research and Innovation Centre, Athenry, Co. Galway, Ireland (54°80'N; 7°25'W), from October 2012 for three production years. The study comprised of three SR pasture systems: a low (LSR; 10 ewes ha^{-1}), a medium (MSR; 12 ewes ha^{-1}) or high (HSR; 14 ewes ha^{-1}). Post-lambing, ewes and lambs were turned out to pasture and grazed in a five paddock rotational system to post-grazing sward height targets of 4.55, 4.15, and 3.75 cm for the LSR, MSR and HSR, respectively. Lambs were weaned on average at 14 weeks of age, with a leader follower grazing system operated post-weaning. Lambs were drafted for slaughter once pre-defined live weight targets of 42, 43, 44, 45 and 46 kg were reached in the months June, July, August, September and October, respectively, to produce a carcass of 20 kg. Nitrogen fertiliser was applied at a rate of 13 kg ewe^{-1} across all treatments. Pre- and post-grazing (> 3.5 cm) herbage mass (kg dry matter (DM) ha^{-1}) was determined for each grazing by harvesting two random strips (1.2 × 10 m) of grass representative of the paddock with an Etesia mower. All mown herbage from the strip was collected, weighed and a 0.1 kg (fresh weight) sub sample taken and dried for 16 hours at 90°C for the calculation of DM content and herbage quality. Lambs that were not drafted by October in each treatment were removed from their grazing farmlet when grass supply dropped below 50 kg DM ewe^{-1} ha^{-1} or lamb growth rate dropped below 100 grams d^{-1} and finished indoors on *ad libitum* grass silage and concentrates. Lamb carcass output ha^{-1} produced from grazed grass alone and total carcass output (includes lambs finished on grass silage and concentrates) was recorded. The effect of SR on herbage utilisation and carcass output were modelled using linear mixed models in PROC HPMIXED (SAS, 2012).

Results and discussion

Total herbage DM production increased ($P < 0.001$) as SR increased (9,574, 10,843, and 13,047) (SEM = 347.2) kg DM ha^{-1}; at the LSR, MSR, and HSR, respectively. The quantity of grazed grass, silage and total herbage utilised was greatest at the HSR, intermediate at the MSR and lowest at the LSR ($P <$ 0.001*;* Table 1). This was a result of the greater SR and lower target PGSH imposed in the MSR and HSR and supports previous findings observed in dairy grazing systems (Macdonald *et al.,* 2008; McCarthy *et al.,* 2012).

The proportion of leaf in the MSR and HSR swards above the target PGSH was 4% greater relative to the LSR ($P < 0.05$), with no significant differences observed in the proportion of stem and dead material. This finding demonstrates the positive effects of increasing SR and grazing severity on sward morphology despite greater pre-grazing herbage masses above the target PGSH and highlights the potential to graze at greater SR and lower into the grazing sward. Stocking rate had no effect on herbage quality, however, the UFL value in grazed herbage in rotation seven (autumn grazing period) was lower than in rotation six (Figure 1; $P < 0.05$).

This is an important factor for lamb producers to consider, especially in intensively stocked grazing systems where the aim is to finish all lambs off pasture; as results from this study demonstrated lifetime lamb average daily gain (ADG; $P < 0.001$) decreases as SR increases (231, 219, 230 (SEM = 2.9) g d^{-1}at the LSR, MSR and HSR, respectively). In addition, HSR lambs (230 d) took longer to reach slaughter ($P < 0.001$) relative to LSR (203 d) and MSR lambs (213 d) which did not differ in days to slaughter. This resulted in a greater number of lambs grazing pasture in the autumn period at the HSR. However, despite lower lifetime ADG as SR increased, total lamb carcass output ha^{-1} increased (321, 368, 424 (SEM = 10.4) kg carcass, at the LSR, MSR and HSR, respectively; $P < 0.001$).

Table 1. Effect of stocking rate (SR)[1] on sward characteristics and herbage utilisation.

Parameter	LSR	MSR	HSR	SEM	*P*-value
Pre-grazing herbage mass (above target PGSH[2]; kg DM ha^{-1})	1,199^{a}	1,282^{ab}	1,316^{b}	34.0	*
Pre-grazing herbage height (cm)	8.2^{a}	8.1^{a}	7.8^{b}	0.11	*
Post-grazing herbage height (cm)	4.3^{a}	4.1^{b}	3.6^{c}	0.06	***
Herbage utilised (kg DM ha^{-1} $year^{-1}$)					
Grazed	7,381^{a}	8,482^{b}	10,809^{c}	298.0	***
Proportion of herbage utilised to target PGSH[3]	1.06^{a}	1.01^{b}	1.02^{b}	0.014	***
Silage	926^{a}	1,555^{b}	2,040^{c}	65.5	***
Total	8,306^{a}	10,038^{b}	12,849^{c}	302.1	***

[1] Stocking rate: LSR = 10 ewes ha^{-1}, MSR = 12 ewes ha^{-1}, HSR = 14 ewes ha^{-1}.

[2] Target PGSH (post-grazing sward height): LSR = 4.55, MSR = 4.15, and HSR = 3.75 cm).

[a,b,c] Within rows under common sub-headings, means with differing superscripts significantly differ. *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, NS = Not significant (P>0.05).

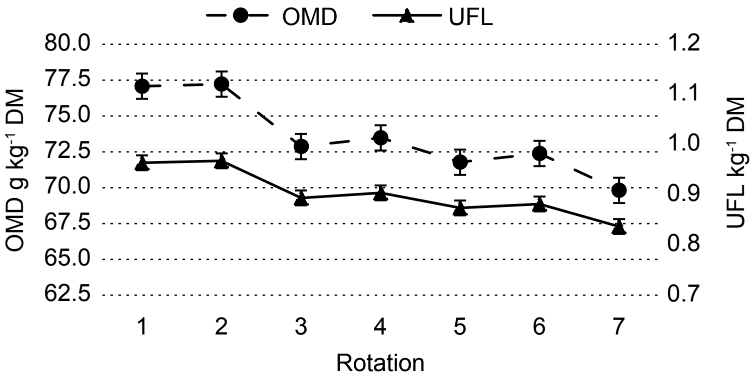

Figure 1. Effect of grazing rotation on sward organic matter digestibility (OMD) and Unite Fourrage Lait (UFL) levels. Error bars represent mean standard error.

Conclusion

Achieving a balance between the supply of high quality pasture and herbage utilization is paramount in optimising temperate grass-based lamb production systems. In the current study, increasing SR and grazing severity increased herbage DM production, utilisation and the proportion of leaf material within the grazing sward, demonstrating the positive effects of SR on sward productivity. In addition, increasing SR also provided the opportunity to increase lamb carcass output ha^{-1}.

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The impact of ewe prolificacy potential and stocking rate on the efficiency of lamb production

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Abstract

A 2 × 3 factorial design study was conducted over three years to determine the effect of ewe prolificacy potential (PP), stocking rate (SR) and their interaction on the efficiency of lamb production from grass-based systems. There were two ewe PP levels; medium prolificacy (MP - Suffolk crossbred ewes, 1.5 lambs ewe^{-1}) and high prolificacy (HP - Belclare crossbred ewes, 1.7 lambs ewe^{-1}) and three SR's, low (LSR; 10 ewes ha^{-1}), medium (MSR; 12 ewes ha^{-1}), and high (HSR: 14 ewes ha^{-1}). The HP treatment produced 50 kg more lamb carcass ha^{-1} ($P < 0.05$) and required 13% less kg DM to produce a kilogram of lamb carcass ($P < 0.001$). Ewe PP had no effect on the total quantity of DM consumed ewe and lamb unit^{-1} ($P > 0.05$). Lamb carcass output (kg ha^{-1}) was highest at HSR, intermediate at MSR and lowest at LSR ($P < 0.001$). The quantity of DM and energy consumed ewe and lamb unit^{-1} and kg of lamb carcass^{-1} produced increased as SR increased ($P < 0.001$). This study demonstrates the potential to increase lamb output and production efficiency from grass through greater ewe PP and SR levels, however, achieving this increase required additional DM ewe and lamb unit^{-1} above 12 ewes ha^{-1}.

Keywords: carcass output, energy consumption, dry matter, prolificacy, stocking rate

Introduction

The production of lamb in temperate grass-based production systems is principally based upon the conversion of herbage into lamb carcass. Successful grazing systems require animals that can efficiently convert feed into a high value product. At present, lamb production systems are limited by the efficiencies at which they operate, such as number of lambs sold and herbage utilisation (Keady *et al.,* 2009). Ewe prolificacy potential (PP; predicted number of lambs born ewe^{-1} year^{-1}) and stocking rate (SR; ewes ha^{-1}) are two of the most influential factors affecting lamb output (Keady *et al.,* 2009) and the efficiency at which feed resources are utilised. At present, there is a paucity of information in regard to the effects of ewe PP, SR and their interaction on efficiency of lamb production. Therefore, the objective of this study was to investigate the effect of ewe PP, SR and their interaction on the efficiency of lamb production in a temperate grass-based system.

Materials and methods

The study was conducted at the Sheep Research Demonstration farm, Teagasc, Animal and Grassland Research and Innovation Centre, Athenry, Co. Galway, Ireland (54°80'N; 7°25'W), from October 2012 for three production years (2013 to 2015). The study had a 2 × 3 factorial design which consisted of two ewe PP levels. This comprised of 180 medium prolificacy (MP) – Suffolk crossbred ewes (1.5 lambs ewe^{-1}), and 180 high prolificacy (HP) – Belclare crossbred ewes (1.7 lambs ewe^{-1}). Within PP, ewes were blocked by live weight (kg) and body condition score (BCS; 1 - 5 scale), before being randomly assigned to one of three SR: a low (LSR; 10 ewes ha^{-1}), a medium (MSR; 12 ewes ha^{-1}) or high (HSR; 14 ewes ha^{-1}). Post-lambing, ewes and lambs were turned out to pasture and grazed in an independent five paddock rotational system to post-grazing sward height targets of 4.55, 4.15 and 3.75 cm for the LSR, MSR and HSR, respectively. Lambs were weaned on average at 14 weeks of age, with a leader follower grazing system operated post-weaning. Lambs were drafted for slaughter once pre-defined live weight targets of 42, 43, 44, 45 and 46 kg were reached in the months June, July, August, September and October, respectively to produce a carcass of 20 kg. Nitrogen fertiliser was applied at a rate of 13 kg ewe^{-1} across all treatments. Lambs that were not drafted by October in each treatment were removed from their grazing farmlet when grass supply dropped below 50 kg dry matter (DM), ewe^{-1} ha^{-1} or lamb growth rate dropped below 100 grams d^{-1} and finished indoors on *ad libitum* grass silage and concentrates. All feed inputs (grazed and conserved herbage and concentrates) were fully quantified. Lamb carcass output produced ha^{-1} was recorded. The quantity of DM and Unite Fourrage Lait (UFL) consumed as grazed herbage, conserved herbage and concentrates on a ewe and lamb unit basis and kilogram of lamb $carcass^{-1}$ produced was calculated based on herbage production data and concentrate feeding reported by Earle *et al.* (2017b). The effect of ewe PP, SR and their interaction on lamb carcass output, total amount of DM and UFL consumed per ewe and lamb unit and kg of lamb $carcass^{-1}$ produced were analysed using a linear mixed model in PROC GLM (SAS, 2012) with ewe PP, SR, year and the interaction between PP and SR included as fixed effects.

Results and discussion

Ewe PP had no effect on the total quantity of DM and UFL consumed per ewe and lamb unit ($P>0.05$). The UFL quantity consumed per ewe and lamb unit as total herbage (grazed and conserved) and total UFL was highest at the HSR ($P < 0.001$) but did not differ between the LSR and MSR. The HP treatment consumed 4.1 kg DM less and 3.7 UFL less $kilogram^{-1}$ of lamb carcass produced compared to the MP treatment (Table 1; $P < 0.001$). The HP treatment had a higher total lamb carcass output ha^{-1} (+50 kg; $P < 0.05$; Table 2). This can be primarily attributed to the greater number of lambs slaughtered ewe^{-1} and the significantly higher carcass weight of progeny born to HP ewes reported by Earle *et al.* (2017a). The increase in lamb carcass output ha^{-1} and 13% higher feed efficiency of the HP system demonstrates it to be more efficient in the production of lamb carcass. Total lamb carcass output ha^{-1} was highest at the HSR, intermediate at the MSR and lowest at the LSR ($P < 0.001$) and supports previous findings by Keady *et al*. (2009). A higher proportion of the total quantity of lamb carcass produced at the HSR was from grazed herbage supplemented with conserved herbage and concentrates relative to the LSR ($P < 0.05$); the MSR did not differ from either. The lower quantity of UFL consumed per kilogram of lamb carcass produced in the LSR treatment is a result of higher lifetime lamb average daily gain, lower days

Table 1. The effect of ewe prolificacy potential (PP)[1] and stocking rate (SR)[2] on the quantity of energy (UFL; Unite fourrage laite)[3] consumed on a ewe and lamb $unit^{-1}$ basis and kilogram of carcass $produced^{-1}$.

Parameter	PP			SR				*P*-value	
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR
UFL consumed ewe and lamb $unit^{-14}$									
Grazed herbage	676	669	5.5	672^a	643^b	703^c	6.7	ns	***
Conserved herbage	95	97	0.5	73^a	102^b	114^c	0.61	*	***
Total herbage	771	766	6.0	744^a	745^a	817^b	7.3	ns	***
Concentrates	30	33	0.3	29.3^a	30.4^b	35.4^c	0.3	***	***
Total UFL	802	799	6.2	774^a	775^a	852^b	7.5	ns	***
UFL consumed kilogram of $carcass^{-1}$									
Grazed herbage	23.4	20.2	0.23	21.0^a	21.1^a	23.4^b	0.28	***	***
Conserved herbage	3.3	3.0	0.04	2.3^a	3.3^b	3.8^c	0.10	***	***
Total herbage	26.7	23.2	0.27	23.2^a	24.4^b	27.2^c	0.34	***	***
Concentrates	0.99	1.06	0.007	0.91^a	0.99^b	1.17^c	0.009	***	***
Total UFL	27.8	24.1	0.28	24.1^a	25.4^b	28.4^c	0.34	***	***

[1] Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

[2] Stocking rate: LSR = 10 ewes ha^{-1}, MSR = 12 ewes ha^{-1}, HSR = 14 ewes ha^{-1}.

[a,b,c] Within rows, means with differing superscripts significantly differ. *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, ns = Not significant ($P > 0.05$).

Table 2. The effect of ewe prolificacy potential (PP)[1] and stocking rate (SR)[2] on the kilogram of lamb carcass produced ha^{-1}.

Lamb carcass output (kg ha^{-1})	PP			SR				*P*-value	
	MP	HP	SEM	LSR	MSR	HSR	SEM	PP	SR
Grazed herbage only[3]	293	334	11.3	291	314	335	13.8	*	ns
Grazed herbage plus supplementation[4]	52.7	62.4	5.4	30.4^{a}	53.7^{ab}	89.0^{b}	6.6	ns	*
Total lamb carcass produced	346	396	8.5	321^{a}	368^{b}	424^{c}	10.4	*	***

[1] Prolificacy potential: MP = medium prolificacy potential, HP = high prolificacy potential.

[2] Stocking rate: LSR = 10 ewes ha^{-1}, MSR = 12 ewes ha^{-1}, HSR = 14 ewes ha^{-1}.

[3] Lamb carcass produced off grazed herbage without any supplementation.

[4] Lamb carcass produced from grazed herbage and supplementation (including concentrates at grass and housed and fed conserved herbage and concentrates).

[a,b,c] Within rows, means with differing superscripts significantly differ. *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, ns = Not significant ($P > 0.05$).

to slaughter and shorter winter housing period for LSR ewes. However, the lack of difference in many of the efficiency parameters measured in the present study such as total UFL consumed per ewe and lamb unit and the proportion of lamb carcass produced from grazed herbage suggests that the LSR and MSR systems are equally efficient in the production of lamb and utilisation of feed resources.

Conclusion

Increasing ewe PP increased lamb carcass output and the efficiency of lamb production in a temperate grass-based production system. The lack of interaction between ewe PP and SR demonstrates the potential to increase ewe PP along with SR in a temperate grass-based lamb production system. The use of higher SR illustrates the potential to increase lamb carcass output ha^{-1}. However, the higher quantities of DM and UFL consumed per ewe and lamb unit above 12 ewes ha^{-1} would indicate a decline in the efficiency of production of lamb at 14 ewes ha^{-1}.

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The effect of genetic merit on post-weaning lamb performance at grass

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Abstract

Post-weaning lamb performance is often sub-optimal on Irish sheep farms. The aim of the study was to compare the post-weaning performance of lambs sourced from three groups (n = 60 ewes per group), that were genetically divergent for maternal traits, namely; high genetic merit New Zealand (NZ), high genetic merit Irish (High) and low genetic merit Irish (Low). Lambs were born in a mid-season lamb production system and ewes were turned out to pasture with an average litter size of 1.55 lambs ewe^{-1}. All lambs were weaned at 100 days of age. Post-weaning a leader follower grazing system was operated whereby lambs grazed ahead of the ewes. Lamb live-weight was recorded on a fortnightly basis with lambs drafted once an adequate fat cover and the targeted live-weights of 43 to 48 kg for months June to November, respectively was achieved. Phenotypes collected from all lambs included live-weight and drafting date. New Zealand and High lambs reached target slaughter weight earlier than Low lambs ($P < 0.05$) while NZ lambs were more likely to finish from a grass based diet when compared to both High and Low lambs ($P < 0.01$); despite similar herbage mass offered and grass utilised among each group.

Keywords: genetics, lamb performance, drafting rates, days to slaughter, weaning

Introduction

Genetic gain is cumulative and permanent, however, progress in the replacement or maternal index through the selection of maternal traits in Ireland has been low (€0.28 lamb year^{-1}) compared to the corresponding gains reported in New Zealand (€1.16 lamb year^{-1}) (Santos *et al.*, 2015). In New Zealand, sheep genetic indexes have been available for sheep farmers for over twenty years with large increases in sheep farm productivity and profitability achieved on a primarily pasture-based system. Essential to the success of an efficient meat-production system is live-weight gain (average daily gain); the primary factor influencing days to slaughter and ultimately, the sale date of the animal. Post-weaning lamb growth rate is often lower than what is achievable, particularly when grazing perennial ryegrass swards (Golding *et al.*, 2011). Therefore, the aim of this study was to investigate the effect of genetic merit, whether high or low and country of origin (New Zealand or Ireland) on the overall growth performance of the lamb in the post-weaning period.

Materials and methods

The study was conducted over two production years, beginning in October 2015 at the Teagasc Animal and Grassland Research Centre, Athenry, Co. Galway.

In total, three groups of animals (n = 60 ewes per group), comprising of two main breeds (Texel and Suffolk), were assembled; representing high genetic merit New Zealand ewes (NZ), high genetic merit Irish ewes (High), and low genetic merit Irish ewes (Low). Animals were selected based on their genotypic evaluations for maternal characteristics which categorised them in the top and bottom 20% of the national population for High and Low (Irish only), respectively. In early October each year, ewes were mated to pedigree Texel and Suffolk sires of similar genetic merit and origin using artificial insemination. The flock was operated as a mid-season lamb production flock, with a mean lambing date of 08 March. Lamb birth-weight, which was similar for all lambs regardless of treatment group, was recorded within

12 hours of birth. Incidences of mortality in the first 48 hours were also recorded. Ewes were turned out to pasture at ~48 hours post-partum with an average rearing litter size of 1.55 lambs ewe^{-1}. All lambs were weaned at 100 days of age with live-weights of 34.9 kg, 33.9 kg and 33.1 kg for NZ, High and Low lambs, respectively. Post-weaning lambs were weighed fortnightly and were drafted from the experimental grazing group using a method replicating that applied on commercial sheep farms. Briefly, once lambs reached 43 kg in June and rising by 1 kg per month to 48 kg live-weight in November, and were deemed to have an adequate fat cover, lambs, in line with the EUROP grading system, were removed from the experimental grazing group. Individual lamb average daily gain (ADG) was calculated as the difference between two weigh points regressed over the subsequent time interval. Once the group mean ADG of lambs declined below 100 g, concentrate supplementation was introduced to all lambs at a rate of 350 g day^{-1}. Days to slaughter were calculated as the duration from birth until a lamb reached their target slaughter weight. The total percentage of lambs drafted from each group consuming a grass only diet was further investigated. Data on post-weaning lamb live-weight, ADG from weaning to drafting and days to slaughter were analysed using a linear mixed model in PROC MIXED (SAS, 2012) with animal genetic merit (NZ, High or Low), breed (Texel or Suffolk), sex, birth type and year included as fixed effects in the model for all animal data. In all models ewe parity was included as the repeated effect and sire of the lamb was included as a random effect in the model.

The NZ, High and Low groups were managed separately in a rotational grazing system with a total allocation of 5 ha per group. In the post-weaning period, a leader follower grazing system was adopted whereby lambs grazed ahead of ewes, with target post-grazing sward height (PGSH) of 5.1 cm for lambs and 4.1 cm for ewes. Inorganic fertiliser nitrogen application rates were applied at a rate of 11 kg Nitrogen (N) ewe^{-1} year^{-1}. Nitrogen was applied prior to the first rotation and after grazing rotations two to six. Pre and post-grazing compressed sward height (CSH) measurements were recorded on each paddock before and after grazing, respectively, by taking 50 measurements across the diagonal of the paddock. The average paddock pre-grazing herbage mass (above target PGSH) was calculated according to the following formula: pre-grazing herbage mass (above PGSH) = ((Pre-grazing CSH (cm) - PGSH (cm)) × sward density); kg DM ha^{-1}. The proportion of herbage utilised to target PGSH and above 3.5 cm at each grazing was determined using the following equation: herbage utilised = (herbage removed/ herbage available (above target PGSH and 3.5 cm) at each grazing). A representative herbage sample was collected and dried at 90 °C for 16 hours for DM determination. Data on pre-grazing herbage mass above PGSH, pre- and post-grazing CSH, proportion of grass utilised to target and to 3.5 cm were analysed using a linear mixed model in PROC MIXED (SAS, 2012) with animal genetic merit (NZ, High or Low) season, rotation and year included as fixed effects.

Results and discussion

Greater milk yields were measured in the NZ and High ewes compared to Low ewes ($P < 0.01$). In the post-weaning period NZ and High lambs had higher ADG compared to Low lambs ($P < 0.05$). This ultimately led to NZ and High lambs reaching 'the target' drafting weight at an earlier age compared to Low lambs ($P < 0.01$; Table 1). Relative to lambs born to High and Low ewes, lambs born to NZ ewes had a greater predicted probability of reaching 'the target' drafting weight from a grass only diet (3.17 ± 1.33 and 4.26 ± 1.29, respectively; $P < 0.01$). These results are in agreement to the findings of Cymru *et al.* (2008) where NZ lambs had tendencies to be superior to high index and national average index lambs from the UK for days to slaughter, and where ADG tended to be greater for NZ and High lambs; albeit investigating a different breeding objective compared to the Irish maternal breeding objective.

Pre-grazing herbage mass (above target PGSH) did not differ between the grazing groups at 1,354 kg DM ha^{-1}, 1,238 kg DM ha^{-1} and 1,230 kg DM ha^{-1} for the NZ, High and Low groups, respectively ($P <$ 0.05). Similarly, the proportion of grass utilised to target PGSH in the first to last grazing system did not

Table 1. Effect of ewe origin (NZ, High and Low) with the associated standard error of the mean and P value, on post-weaning live-weight, average daily gain from weaning to drafting and from birth to drafting and number of days to slaughter.[1]

	New Zealand	High	Low	SEM	*P*-value[2]
Drafting weight, kg	46.1	45.6	45.8	0.32	ns
Average daily gain, g					
Weaning-drafting	223[a]	220[a]	190[b]	22.0	*
Lifetime (birth-drafting)	256[a]	245[ab]	232[b]	8.91	*
Days to slaughter, days	160[a]	165[a]	175[b]	4.66	**

[1] a,b,c Within rows, means with differing superscripts significantly differ.

[2] *, ** Equates to $P < 0.05$, $P < 0.01$.

differ between the three genetic groups (NZ = 1.06, High = 1.08, Low = 1.06; $P > 0.05$) and supports work carried out by Earle *et al.* (2017) where ewe stocking rate and prolificacy potential were investigated in an Irish sheep flock. Earle *et al.* (2017) demonstrated that ewes stocked at 12 ewes ha^{-1}achieved similar grass utilisation figures to those reported herein.

Conclusion

Results to date demonstrate the suitability of lambs from high genetic merit ewes, irrespective of origin (i.e. NZ or Irish) to an Irish pasture-based production system.

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Interaction of early lactation pasture allowance and duration on cumulative milk production

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Abstract

Fluctuations in spring grass growth can create deficits in grass supply during the early lactation period in Irish dairy production systems. The objective of this experiment was to investigate if different pasture allowances offered to early lactation grazing dairy cows for varying time durations influenced cumulative milk yield and composition produced during the first 33 weeks of the experiment. The two-year experiment offered cows one of four pasture allowances (PA; 60, 80, 100 or 120% of calculated intake capacity) for either two or six weeks. Once the two- and six-week time durations had elapsed, all cows were offered 100% of intake capacity. Data were analysed using mixed models in PROC MIXED (SAS; v9.4). There was a tendency ($P = 0.06$) for an interaction between duration and PA for cumulative milk yield. Offering 120% for six weeks increased milk yield (4,270 kg cow^{-1}) compared to 80 × 2, 100 × 2, 60 × 6 and 80 × 6. All cows other than the 120 × 6 were similar (3,957 kg cow^{-1}). There was no effect of PA or duration on milk fat, protein and lactose content. This suggests that when cows are offered more than they require to achieve IC for a six-week period (120 × 6), cumulative milk yield is higher compared to those offered a restricted PA for an extended period of time (six weeks).

Keywords: pasture allowance, early lactation, dairy cow

Introduction

Overcoming fluctuations in milk price to help maintain farm profitability can be achieved by maximising utilisation of grazed pasture, the cheapest feed available in temperate climates (Finneran *et al*., 2012). However, pasture availability deficits in Ireland can arise due to low early spring growth. This is compounded by increasing herd size and more compact calving patterns (ICBF, 2017) creating a higher demand for pasture in the early spring period. A 10-week restriction of pasture allowance (PA) in early lactation has previously been shown to reduce immediate milk production but cumulative milk production was unaffected (Ganche *et al*., 2013). However, fluctuations in pasture availability are more likely to occur for shorter periods of time in spring. The objective of this experiment was to investigate if different pasture allowances offered to early lactation grazing dairy cows for either two or six weeks influenced cumulative milk production produced during the 33 week long experiment.

Materials and methods

Ninety six dairy cows were assigned to a randomised complete block design with a 4 × 2 factorial arrangement of treatments in an experiment which was repeated over two years (25 March to 27 November 2014 and 9 March to 23 November 2015). Cows (41 primiparous and 55 multiparous in year one (Y1); 24 primiparous and 72 multiparous in year two (Y2)) were balanced on calving date (17 February, s.d. 15.5 d, Y1; 9 February, s.d. 8.4 d; Y2), breed (Holstein-Friesian, n = 52; Jersey × Holstein-Friesian, n = 38; Norwegian Red, n = 6, Y1; Holstein-Friesian, n = 43; Jersey × Holstein-Friesian, n = 34; Norwegian Red, n = 19, Y2), lactation number (2.4, s.d. 1.61, Y1; 2.6, s.d. 1.50, Y2) and production variables from the two weeks prior to the start of the experiment: milk yield (22.6, s.d. 4.20 kg d^{-1}, Y1; 25.2, s.d. 3.88 kg d^{-1}, Y2), milk fat (55.8, s.d. 9.18 g kg^{-1}, Y1; 51.7, s.d. 7.10 g kg^{-1}, Y1), milk protein

(34.5, s.d. 3.00 g kg^{-1} Y1; 34.8, s.d. 2.42 g kg^{-1} Y2) and milk lactose (46.9, s.d. 1.87 g kg^{-1}, Y1; 47.0, s.d. 1.34 g kg^{-1}, Y2) concentration, milk solids yield (2.03, s.d. 0.408 kg d^{-1} Y1; 2.17, s.d. 0.350 kg d^{-1} Y2), bodyweight (BW; 469, s.d. 68.2 kg, Y1; 523, s.d. 58.1 kg, Y2) and body condition score (BCS; 3.09, s.d. 0.193, Y1; 3.17, s.d. 0.167, Y2). Cows were then randomly assigned to one of four PA (60, 80, 100 or 120% of intake capacity; IC) for either two or six weeks. Once the two- and six-week time durations had elapsed, all cows were offered 100% of IC. Intake capacity was calculated using the equation of Faverdin *et al.* (2011) based on age, parity, days in milk, BW, BCS and potential milk yield. Pasture allowance (> 3.5 cm) for the 60, 80 and 120% treatments were calculated based on the IC of the 100×6 treatment. Treatment groups grazed adjacent to each other to ensure similar HM was offered. Herbage mass (HM; > 3.5 cm) was measured twice weekly by cutting 6 strips (120 m^2) per grazing area. As HM was similar between treatments daily area allocations differed. Pre- and post-grazing sward heights were measured daily using a rising plate meter. Fresh pasture areas were offered after each milking while treatments were being imposed and on a 24-hour basis thereafter. Milk yield was recorded daily, individual cows daily yields were summed to calculate cumulative milk yield following the 33-week experimental period. Data were analysed using covariate analysis and mixed models in SAS v9.4. Terms for year, parity, breed, PA, duration and the interaction of PA and duration were included. Pre-experimental values were used as covariates in the model.

Results and discussion

There was a tendency ($P = 0.06$) for an interaction between duration and PA for cumulative milk yield (Figure 1). Cows assigned to the 120 × 6 treatment had a higher cumulative milk yield (4,270 kg cow^{-1}) than the 80 × 2, 100 × 2, 60 × 6 and 80 × 6 treatments. All cows other than the 120 × 6 were similar (3,957 kg cow^{-1}). Following the first ten weeks of the experiment (six weeks when different PA were imposed and four weeks when 100% IC was offered) the 120×6 treatment produced more milk (+ 44 kg cow^{-1}) than all other treatments during this period. This was due to their higher dry matter intake; in this study there was a linear response to PA when DMI was measured at weeks two and six of the experiment; for every 10% increase in PA, DMI increased by 0.65 and 0.56 kg cow^{-1} day^{-1}, respectively (Kennedy *et al.,* 2018). However, a six-week period is relatively short in the context of a 33 week long experiment; consequently it gave the other treatments an opportunity to increase their milk production when IC was restored to 100%. Nevertheless, a six-week PA restriction (60 × 6 and 80 × 6) in early lactation did

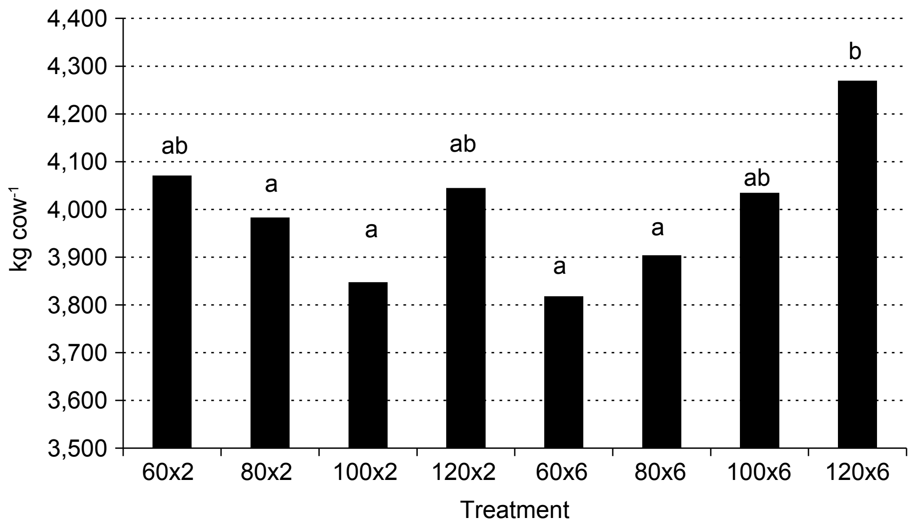

Figure 1. Effect of early lactation treatment on 33-week milk yield ($P = 0.06$).

reduce cumulative milk yield in comparison to offering 120% IC however, cumulative milk yield of these treatments was similar to the control treatment (100 × 6). As the 100 × 6 and 120 × 6 treatments were similar it suggests that there was no advantage in offering additional grass over and above cows IC in early lactation. There was no effect of PA or duration on 33-week average milk fat (4.75%), protein (3.61%) and lactose (4.71%) content.

Conclusion

The results of this experiment suggest that when cows are offered more than they require to achieve IC for a six-week period (120×6), cumulative milk yield is higher compared to those offered a restricted PA for an extended period of time (six weeks). However, decisions on feeding the early lactation dairy cow need to incorporate effects on animal behaviour and welfare as well as production.

Acknowledgements

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Interaction of early lactation pasture allowance and duration on dry matter intake

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Abstract

The objective of this experiment was to investigate if different pasture allowances offered to early lactation (40 days in milk at experiment start) grazing dairy cows for varying time durations influenced dry matter intake (DMI) measured at weeks two, six and 12 of the experiment. The two year experiment offered cows one of four pasture allowances (PA; 60, 80, 100 or 120% of intake capacity; IC) for either two or six weeks; PA was based on the 100% IC treatment, as their DMI increased all other PA increased proportionately. Once the two- and six-week time durations had elapsed, all cows were offered 100% IC. Dry matter intake was estimated using the *n*-alkane technique. Data were analysed using mixed models in PROC MIXED (SAS; v9.4). There was a linear response to PA when DMI was measured at two and six-weeks; for every 10% increase in PA, DMI increased by 0.65 and 0.56 kg cow^{-1} day^{-1}, respectively. At six weeks there was no difference in DMI of cows offered differing PA for a two week duration (15.4 kg cow^{-1} day^{-1}). When all cows were offered 100% IC and DMI was measured at week 12, there was no effect of PA or duration on DMI (16.5 kg cow^{-1} day^{-1}). This suggests that in early lactation there is an effect of PA on DMI but any effects disappear when cows are offered 100% IC.

Keywords: pasture allowance, early lactation, dairy cow, dry matter intake

Introduction

In Ireland, pasture growth is highly seasonable with little or no growth over the winter months (Hurtado-Uria *et al*., 2013), resulting in deficits in pasture supply during the early spring period. The majority of Irish cows calve during early spring (AIMS, 2016) creating a high demand for any available pasture. As grazed grass is the cheapest feed available (Finneran *et al*., 2012) its utilisation needs to be maximised, with minimal reliance on concentrate input to maintain farm profitability. However, a balance needs to be achieved between feeding the early lactation dairy cow and utilising the maximum amount of pasture. Previous studies have included concentrate to overcome deficits in feed supply (Ganche *et al*., 2013) but given fluctuations in milk price and the requirement to maintain farm profitability, systems which rely solely on pasture need to be investigated. The objective of this experiment was to investigate if different pasture allowances offered to early lactation grazing dairy cows for varying time durations influenced dry matter intake (DMI) measured at weeks two, six and 12 of the experiment.

Materials and methods

The study was carried out over a two year period; from 25 March to 27 November 2014 and 9 March to 23 November 2015. Each year 96 dairy cows (41 primiparous and 55 multiparous in year one (Y1); 24 primiparous and 72 multiparous in year two (Y2)) were assigned to a randomised complete block design with a 4×2 factorial arrangement of treatments. Cows (41 primiparous and 55 multiparous in year one (Y1); 24 primiparous and 72 multiparous in year two (Y2)) were balanced on calving date (17 February, s.d. 15.5 d, Y1; 9 February, s.d. 8.4 d; Y2), breed (Holstein-Friesian, n = 52; Jersey × Holstein-Friesian, n = 38; Norwegian Red, n = 6, Y1; Holstein-Friesian, n = 43; Jersey × Holstein-Friesian, n = 34; Norwegian Red, n = 19, Y2), lactation number (2.4, s.d. 1.61, Y1; 2.6, s.d. 1.50, Y2) and production variables from the two weeks prior to the start of the experiment: milk yield (22.6, s.d. 4.20 kg d^{-1}, Y1; 25.2, s.d. 3.88 kg d^{-1}, Y2), milk fat (55.8, s.d. 9.18 g kg^{-1}, Y1; 51.7, s.d. 7.10 g kg^{-1}, Y1), milk protein (34.5, s.d. 3.00 g kg^{-1} Y1; 34.8, s.d. 2.42 g kg^{-1} Y2) and milk lactose (46.9, s.d. 1.87 g kg^{-1}, Y1; 47.0, s.d. 1.34 g kg^{-1}, Y2) concentration, milk solids yield (2.03, s.d. 0.408 kg d^{-1} Y1; 2.17, s.d. 0.350 kg d^{-1} Y2), bodyweight (BW; 469, s.d. 68.2 kg, Y1; 523, s.d. 58.1 kg, Y2) and body condition score (BCS; 3.09, s.d. 0.193, Y1; 3.17, s.d. 0.167, Y2). Cows were then randomly assigned to one of four PA (60%, 80%, 100% or 120% of intake capacity; IC) for either two or six weeks. Once the two- and six-week time durations had elapsed, the treatments were offered 100% IC. Intake capacity was calculated using the equation of Faverdin *et al*. (2011) based on age, parity, days in milk, BW, BCS and potential milk yield. Pasture allowance was on average 13.4 kg DM cow^{-1} day^{-1} during the first two weeks and this increased to an average of 15.1 kg DM cow^{-1} day^{-1} during weeks three to six. Pastures were > 80% perennial ryegrass. Fresh pasture areas were offered after each milking while treatments were being imposed and on a 24-hour basis thereafter. Pre- and post- grazing sward heights were measured daily using a rising plate meter. Herbage mass (HM; > 3.5 cm) was measured twice weekly by cutting six strips (120 m^2) per grazing area. Treatment groups grazed adjacent to each other to ensure similar HM was offered. Pasture allowance (> 3.5 cm) for the 60, 80 and 120% treatments were calculated based on the IC of the 100×6 treatment; however, cows were able to increase their DMI by grazing below the 3.5 cm sward horizon. As HM was similar between treatments, daily area allocations differed. Dry matter intake was estimated using the *n*-alkane technique (Dillon and Stakelum, 1989) during weeks two, six and 12 of the experimental period. During week two all treatments were offered their respective PA, during week six, the two-week cows were offered 100% IC while the six week treatments still remained on their respective PA treatments. During week 12 all cows were offered 100% of their IC. Data were analysed using covariate analysis and mixed models in SAS v9.4. Terms for year, parity, breed, PA, duration and the interaction of PA and duration were included. Pre-experimental values were used as covariates in the model.

Results and discussion

There was a linear response to PA when DMI was measured at weeks two and six of the experiment; for every 10% increase in PA, DMI increased by 0.65 and 0.56 kg cow^{-1} day^{-1}, respectively (Table 1).

In early lactation dairy cows have rising nutritional requirements, as observed with the increased DMI of the 100 and 120% treatments between weeks two and six of the experiment. This increased demand for nutrients is also reflected in the actual DMI of the cows allocated 60% IC; they consumed 21 and 17% less during weeks two and six of the experiment, respectively compared to their 100% IC counterparts who were initially offered a 40% greater PA. As the diet of the 60% IC cows was restricted they had to graze below the recommended post-grazing sward height horizon of 3.5 cm to increase their DMI as much as possible. Similarly, the 80% treatments DMI were only 10% less than the 100% IC during week two and six. At six weeks there was no difference in DMI of cows offered differing PA for 2 week duration (15.4 kg cow^{-1} day^{-1}); their DMI was similar to their predicted IC. When all cows were offered

Table 1. Dry matter intake during week two and six of experiment of early lactation dairy cows offered 1 of 4 pasture allowances[1] for either two or six weeks.

	Pasture allowance (%IC)				SEM	PA contrast linear	PA signif
	60	80	100	120			
Week 2	10.6[a]	12.0[b]	13.5[c]	14.4[d]	0.203	0.65 (0.046)	0.001
Week 6 (2 wk cows)	15.6	15.6	15.2	15.0	0.287		0.554
Week 6 (6 wk cows)	12.7[a]	13.9[b]	15.3[c]	16.0[d]	0.371	0.56 (0.085)	0.001

[1] 60, 80, 100 or 120% of intake capacity (IC); PA = Pasture allowance; SEM = standard error of the mean; wk = weeks; [a,b,c] superscripts denote significant differences between treatments.

100% IC and DMI was measured at week 12 there was no effect of PA or duration on DMI (16.5 kg cow^{-1} day^{-1}; $P = 0.578$).

Conclusion

The results of this study suggest that in early lactation there is an effect of PA on DMI but any effects disappear when cows are offered 100% IC. However, all other variables such as cow BW and BCS and fertility need to be considered in order to obtain a complete picture of the residual effects of altering PA in early lactation.

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Predicting dry matter intake of grazing dairy cows using near infrared reflectance spectroscopy

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Abstract

Genetic improvements in feed efficiency require phenotypic records on thousands of animals. Tools to predict dry matter intake (DMI) should be accurate, low-cost, facilitate prediction at multiple time points and be amenable for use in a very large population of commercial animals. The aim of this study was to evaluate the potential of Near Infrared Reflectance Spectroscopy (NIRS) analysis of faeces in combination with parity to predict the DMI of grazing dairy cows. Faecal samples were obtained from three different grazing experiments where DMI was available from 142 cows with 380 DMI estimates. Dried and milled faecal samples were scanned at 2 nm intervals over a wavelength range of 1,100-2,500 nm to measure NIRS absorbance. Partial least squares regression was used to develop an equation to predict DMI using *n*-alkane predicted DMI values. The developed equations were moderately accurate with a mean bias of 0.06 kg, slope between true and predicted values of DMI of 0.88 and a coefficient of determination between true and predicted values of DMI of 0.53. Equations developed using faecal NIRS wavelengths and parity show potential at predicting the DMI of grazing dairy cows.

Keywords: DMI, NIRS, faeces

Introduction

Feed efficiency in dairy cows is seen as an area of increasing importance in addressing the problem of feeding a rising and more affluent global human population (Berry and Crowley, 2013). The major obstacle to a rapid increase in feed efficiency in dairy animals is access to large amounts of cost effective and accurate feed intake data (Connor, 2014). In grazing dairy animals, the *n*-alkane technique is the method of choice to determine individual dry matter intake (DMI) but is extremely labour intensive and only suited to research environments (Mayes *et al.*, 1986, Dillon and Stakelum, 1989).

Near Infrared Reflectance Spectroscopy (NIRS) analysis of faeces has previously been explored to predict intake across a range of grazing ruminants (Decruyenaere, 2015). One study by Garnsworthy and Unal (2004), with stall fed lactating dairy cows noted that the technique was as accurate as the *n*-alkane technique in predicting DMI. There has been no research on the ability of faecal NIRS analysis to predict intake of grazing dairy animals estimated through the *n*-alkane technique.

The objective of this study was to assess the ability of faecal NIRS analysis to rapidly predict the DMI of grazing dairy cows.

Materials and method

A faecal sample set comprising 380 samples with corresponding DMI values from 142 individual spring-calving Holstein-Friesian cows (mean calving date: 15 February) were available from three grazing research experiments conducted by Teagasc, Animal and Grassland Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland. Individual herbage DMI was estimated within each experiment using the *n*-alkane technique and faecal grab samples (Mayes *et al.*, 1986) as modified by Dillon and Stakelum (1989). The diet of the cows during the *n*-alkane measurement period consisted predominantly of grazed pasture *(Lolium perenne)*. There were 195 grass only DMI records, there were a further 119 DMI records with supplementation of concentrates (1 to 3 kg) during periods of pasture deficit in spring and 66 DMI records from autumn.

Faecal reflectance and absorbance values from each sample were gathered using a FOSS-NIRSystem 6500 SYII scanning monochromator (FOSS-NIRSystems, Silver spring, MD, USA). The spectral absorbance values were recorded at 2 nm intervals over the wavelength range of 1,100 - 2,500 nm. The spectral absorbency value was conveyed as log 1/R (R = reflectance value).

Partial least squares regression (PROC PLS; SAS Institute Inc., Cary NC) was used to predict kg DMI using faecal NIR wavelengths, experiment, parity and days in milk (DIM) as predictor variables and only variables that contributed towards prediction accuracy were retained in the final model. Three separate calibration equations were developed and independently validated; each equation was calibrated using data from two of the three experiments and validated using the third experiment. Split-sample cross validation was used to develop the model, whereby every 20th sample from the calibration data set was removed and predicted using data from the remaining calibration set.

Results and discussion

Mean DMI, as estimated by the *n*-alkane technique, was 14.1, 17.8 and 16.6 kg cow^{-1}, while mean lactation number was 2.9, 2.7 and 3.4 for experiments 1, 2 and 3, respectively.

The number of samples used for validation ranged from 53 (experiment 2) to 182 (experiment 3). Faecal NIR wavelengths and parity contributed towards prediction accuracy and so remained within the model. Accuracy in cross-validation (R^2 = 0.67 to 0.71) was greater than accuracy in external validation (R^2 = 0.49 - 0.56; Table 1). The slope between true and predicted values was less than one for all experiments and root mean square error (*RMSE*) ranged from 1.80 - 2.26 kg. Inclusion of parity as a predictor improved prediction accuracy (R^2 increased from 0.26 to 0.53); using parity number alone to predict intake explained 0.26 of the variation in DMI. Since equations were calibrated from data obtained from the *n*-alkane technique which is an estimation in itself, a prediction accuracy of near unity was not expected (McParland and Berry, 2016).

Although there is a relationship between faecal NIR spectra and DMI, based on current analysis this relationship is not strong enough to form a reliable prediction equation on its own; however, the incorporation of easily obtainable data such as parity can significantly increase the accuracy of prediction. Johnson *et al.* (2017) reported an R^2 of 0.15 which was developed solely with faecal NIR wavelengths.

Table 1. Fitting statistics[1] of cross- and external-validation prediction equations to predict DMI.

Cross-validation				External-validation						
Calibration[2]	No.	RMSE	R^2	Validation	No.	Bias	RMSE	Slope (SE)	RPD	R^2
1 & 2	198	1.78	0.67	3	182	0.10	2.26	0.97 (.07)	1.4	0.49
2 & 3	235	1.77	0.68	1	145	0.03	1.97	0.76 (0.06)	1.43	0.52
1 & 3	327	1.80	0.71	2	53	0.04	1.80	0.92 (0.11)	1.5	0.57

[1] No = number of samples; RMSE = root mean square error; RPD = ratio performance deviation; R^2 = co-efficient of determination between true and predicted values.

[2] Experiment 1 = (Kennedy *et al.* unpublished); Experiment 2 = (McClearn *et al.* unpublished); Experiment 3 = (Coffey *et al.*, 2017).

Conclusion

This study demonstrates the potential of equations developed using faecal NIR wavelengths and parity to predict the DMI of grazing dairy cows, offering a potential solution to generate intake data at commercial farm level in a less laborious manner than the current gold standard *n*-alkane technique. Further research is warranted to determine if the robustness of the equation can be improved.

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Effects of feeding strategy on milk production and body condition score of dairy cows with differing genetic merit

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Abstract

Holstein Friesian cows, ranked for genetic merit (G) using Ireland's Economic Breeding Index (EBI), were categorised to represent the top 1% (ELITE; n = 90), and the national average (NA; n = 45). The grazing season was divided into three periods (P1 – 12 weeks; P2 – 18 weeks; and P3 – 12 weeks). Three feeding treatments (FT) in spring (P1) and autumn (P3): (1) control (C); (2) low grass allowance (LGA); and (3) high concentrate (HC) treatment were examined. Target post grazing residual height for P1 and P3 was 4.5 cm for C and HC treatments and 3.5 cm for the LGA treatment. Concentrate, 3 kg cow^{-1} day^{-1}, was offered to C and LGA cows throughout P1, whilst 7 kg cow^{-1} day^{-1} concentrate was offered to HC cows. Concentrate supplementation in P3 was 0 kg cow^{-1} day^{-1}, for C and LGA cows respectively, and 4 kg cow^{-1} day^{-1} for HC cows. Feeding treatment had an effect on milk yield ($P < 0.05$) and milk solids ($P < 0.05$) in P1 and P3. Feeding treatment had an impact on BCS ($P < 0.05$) in P1. There was no G*FT interaction evident for any outcome variable. Feeding treatment in early and late lactation had an impact on milk production and BCS.

Keywords: nutrition, milk production, body condition score, dairy cows

Introduction

The range of environments under which dairy cows are managed worldwide makes the understanding of the relationship in which differing genotypes interact with various environments paramount (Horan *et al.,* 2005). Seasonal calving pasture-based production systems rely on a dairy cow that can efficiently convert grass into milk solids (MS; kg fat plus protein). Findings from phase one from the Teagasc Next Generation Herd indicated a significant difference between elite and national average cows for milk solids (MS) yield and body condition score (BCS; O'Sullivan *et al.,* 2016). Nutrition influences performance in cattle through its concurrent and carryover effects on milk production, milk constituents and condition score. Feed fluctuations can be symptomatic in seasonal calving pasture-based dairy systems, particularly in the shoulders of the grazing season. Therefore, the objective of this study was to investigate if there was an interaction between early and late lactation feeding management and genetic merit on milk production and BCS.

Materials and methods

One hundred and thirty five spring calving Holstein Friesian cows, ranked for genetic merit (G) using the economic breeding index (EBI; Irish Cattle Breeding Federation, May 2017), were categorised into those representing the top 1% (ELITE – mean EBI €169; n = 90), and the national mean genetic merit (NA – mean EBI €66; n = 45 cows). The experimental period of 42 weeks was divided into three time periods (P1 – 12 weeks, P2 – 18 weeks and P3 – 12 weeks). Three contrasting feeding treatments (FT) during the spring and autumn (P1 and P3) of the grazing season: (1) control (C); (2) low grass allowance (LGA); and (3) a high concentrate (HC) treatment were examined. Target post grazing residual height for P1 and P3 was 4.5 cm for both C and HC treatments compared with 3.5 cm for the LGA group. Concentrate, 3 kg cow^{-1} day^{-1}, was offered to C and LGA cows throughout P1 to supplement pasture availability, whilst 7 kg cow^{-1} day^{-1} concentrate was offered to HC cows during the same time period. Throughout P2, all cows were managed under a common feeding treatment (4.5 cm post grazing residual and no concentrate supplementation). Concentrate, 4 kg cow^{-1} day^{-1}, was offered to HC cows in P3, whilst C and LGA were offered a grass only diet in the same period. Thirty ELITE (n = 30) and 15 NA (n = 15) cows were randomly allocated to each treatment.

All cows were milked twice daily and samples to measure yield and MS (fat + protein kgs) were collected on a weekly basis. All cows were body condition scored fortnightly before and after calving. Body condition score (BCS) was measured on a scale of 1 - 5 (Edmonson *et al.,* 1989).

The sum of weekly milk yield (kg) and MS (kg) yield were calculated during both P1 and P3, respectively. Mean BCS was calculated from the BCS measurements taken over P1 and P3, respectively. All statistical analyses were carried out using procedures of Statistical Analysis Systems (SAS version 9.1.2 SAS Institute Inc., Cary NC, USA 2004). Outcome variables relating to milk production and BCS were analysed using the PROC GLM procedure. Terms for parity, days in milk, G, FT and G × FT interactions were included in the model.

Results and discussion

The effect of G and FT on milk yield, MS and BCS during P1 and P3 of the grazing season is outlined in Table 1. There was no G*FT interaction evident for the outcome variables measured. Mean ± standard error of mean (sem) post grazing residuals throughout P1 were 3.61 ± 0.07 cm, 4.47 ± 0.09 cm and 4.48 ± 0.09 cm for LGA, HC and C treatments, respectively. Mean ± sem post grazing residuals throughout P3 were 3.96 ± 0.10 cm, 4.47 ± 0.09 cm and 4.53 ± 0.10 cm for LGA, HC and C treatments, respectively. The ELITE and NA cows had a mean milk yield of 1,799 ± 27 and 1,853 ± 37 kg ($P > 0.05$) in P1, respectively, and 1001 ± 26 vs 989 ± 36 kg ($P > 0.05$) in P3, respectively. ELITE and NA cows had a mean MS yield of 149 ± 2 and 149 ± 3 kg ($P > 0.05$) in P1, respectively and 95 ± 2 and 89 ± 3 kg (P = 0.09) in P3, respectively. Mean pre-calving BCS was 3.33 ± 0.02 and 3.20 ± 0.03 ($P < 0.05$) for ELITE and NA cows, respectively.

Table 1. The effect of genotype (G) of Holstein-Friesian and feeding treatment (FT) on milk yield, milk solids yield (MS; kg fat + protein) and body condition score (BCS) in spring (P1) and autumn (P3) of the grazing season.[1]

	ELITE			NA			Sig		
	C	HC	LGA	C	HC	LGA	G	FT	G × FT
Milk Yield P1 (kg)	1,771 (45)	1,931 (46)	1,698 (45)	1,867 (66)	2,001 (62)	1,693 (64)	ns	***	ns
Milk yield P3 (kg)	999 (45)	1,147 (44)	859 (44)	983 (64)	1,203 (59)	780 (61)	ns	***	ns
MS P1 (kg)	146 (4)	159 (4)	140 (4)	151 (5)	159 (5)	137 (5)	ns	***	ns
MS P3 (kg)	97 (4)	107 (4)	82 (4)	91 (5)	108 (5)	69 (5)	0.09	***	ns
BCS									
Mean BCS P1	3.09 (0.04)	3.11 (0.04)	3.01 (0.04)	2.88 (0.05)	3.00 (0.05)	2.78 (0.05)	***	**	ns
Mean BCS P3	2.81 (0.04)	2.83 (0.04)	2.74 (0.04)	2.60 (0.05)	2.75 (0.05)	2.66 (0.05)	**	0.09	ns

[1] P1 = Experimental week 1-12; P3 = Experimental week 31-42; C = Control; HC = High concentrate; and LGA = Low Grass Allowance. Standard error of mean is given in parentheses.

Conclusion

Although these are preliminary results, there are indications that different feeding strategies during spring and autumn have an impact on milk production and body condition score in dairy cows with differing genetic merit. Further data will be required to determine the long term impact of these feeding strategies on cow performance and BCS.

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Comparative grazing behaviour of beef suckler cows of diverse genetic merit

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Abstract

The aim of this study was to compare grazing behaviour of suckler cows of high (n = 42) and low (n = 35) genetic merit for maternal traits. Grazing behaviour was determined at 159 (SD 21.1) and 178 (SD 21.3) days in milk (DIM) using Institute of Grassland and Environmental Research grazing behaviour headset recorders. Cows were managed under a rotational grazing system. Data were analysed using a linear mixed model with genotype, breed, DIM, parity and calving date included as fixed effects; random effect accounted for the repeated records per cow. Variables investigated included live weight, body condition score, grazing time (546 and 564 minutes for high and low, respectively), grazing bout duration (82 and 75 minutes for high and low, respectively), number of bites (30,233 and 29,803 bites for high and low, respectively) ruminating time (416 and 409 minutes for high and low, respectively) and ruminating bout duration (38 and 37 minutes for high and low, respectively). No difference was observed between high and low genetic merit suckler cows for any of the variables investigated. Results from this study suggest no difference exists in grazing behaviour between suckler cows of high and low genetic merit for maternal traits.

Keywords: beef, cows, grazing behaviour, genetics

Introduction

Spring calving suckler cow systems should focus on cows consuming sufficient quantities of grazed pasture and efficiently converting this to milk production to generate a heavy calf at weaning. Behaviour surrounding grazing can dictate the suitability of a beef cow to grass-based systems, with numerous studies reporting differences amongst dairy cow breeds in their grazing and ruminating behaviour which was reflected in performance (Prendiville *et al.,* 2010; Vance *et al.,* 2012). Although studies have investigated grazing behaviour of beef cows, these studies tended to focus on extensive rangeland grazing conditions (Lathrop *et al.*, 1988; Funston *et al.*, 1991). Consequently, the objective of this study was to investigate if differences in grazing behaviour exist between beef cows diverse in genetic merit for maternal traits under Irish intensive pasture-based conditions.

Materials and methods

This study was carried out at Teagasc, Grange Beef Research Centre, Co. Meath, Ireland during August and September, 2015. Heifers for this trial were sourced in 2013 and 2014 at approximately eight months of age from the national suckler herd. Only heifers bred from Aberdeen Angus and Limousin sires of high reliability (> 70%) for the Irish national maternal genetic index, the Replacement Index, were used. Heifers were divided into two groups based on their genetic merit for maternal traits within the index as outlined by McCabe *et al.* (2017) and managed to calve for the first time at 24 months of age. Data were available from 77 cows of first and second parity, 42 high (€118) and 35 low (€45) genetic merit cows for the Replacement Index. Mean calving date was 25 March 2015 and all cows and their calves were turned out to pasture between March and April. Cows were managed under a rotational grazing system on a predominantly perennial ryegrass (*Lolium perenne*) sward. Pre- and post- grazing sward heights were recorded with a rising plate meter (Filip's Manual Plate Meter, Grasstec, Cork, Ireland). During the measurement period pre- and post- grazing sward heights were 10.6 (SD = 1.79) cm and 4.2 (SD = 0.74) cm, respectively. Cow live weight (BW) was recorded at three week intervals using a calibrated 'Titan Weigh Crate' (O'Donovan's Engineering, Cork, Ireland) with Tru-Test software (New Zealand). Body condition score (BCS) was measured concurrently to BW by a single evaluator on a scale of 0 to 5. Grazing behaviour data were recorded twice during lactation at 159 (SD 21.1) and 178 (SD 21.3) days in milk (DIM). Cows were fitted with Institute of Grassland and Environmental Research headset behaviour recorders for a 24 hour period to determine the diurnal patterns of grazing behaviour. To acclimatise the animals to the headsets, a head collar was fitted to each cow 24 hours before applying the grazing headsets. Data were collated and analysed using Graze analysis software (Rutter, 2000). Behaviour measurements extrapolated were: grazing and ruminating time (minutes day^{-1}), number of grazing and ruminating bouts, number of grazing bites, number of grazing and ruminating mastications, and number of ruminating boli, bite rate, grazing and ruminating bout duration and ruminating mastications. Grazing behaviour measurements were analysed using a mixed model in PROC MIXED (SAS Inst. Inc., Cary, NC), with cow genotype (high or low genetic merit), sire breed (Angus or Limousin), DIM, cow parity (1 or 2) and calving date. Cow was included as a repeated measure within all models.

Results and discussion

Few studies have examined the grazing and ruminating behaviour of lactating beef cows; a trait of importance to a pasture-based system, including Ireland. Previous work on dairy cows of varying genetic merit has illustrated how differences in grazing behaviour can influence cow production performance (McCarthy *et al.*, 2007), highlighting the potential to possibly identify beef cow genetics with an affinity to specialised grazing systems. Cow BW and BCS were the same across genetic merit, with BW 641 and 655 kg, and BCS 3.01 and 3.13 for high and low genetic merit cows, respectively. No significant difference in any of the grazing behaviour variables was observed between beef cows of diverse genetic merit for the Replacement Index (Table 1). The length of time cows spent grazing in this study was 72 and 54 minutes less for high and low genetic merit, respectively, than observed by Da Silva *et al.* (2013) on two year old Nelore and Canchim heifers in August at 618 minutes. At 9.1 and 9.4 hours for high and low, respectively, it was similar to that found by Lathrop *et al.* (1988) who recorded grazing times of 9.2 to 9.6 hours. In the current study, high and low genetic merit cows spent 6.9 and 6.8 hours

Table 1. Grazing and ruminating behaviour of beef cows of diverse genetic merit (high versus low) for maternal traits, with the association weighted standard error of the mean and *P*-value.

	Genetic merit		s.e.	*P*-value
	High	Low		
Live weight (kg)	641	655	17.0	NS
Body condition score (0 to 5)	3.01	3.13	0.07	NS
Grazing time (min d-1)	546	564	13.5	NS
Grazing bouts (n d^{-1})	7.6	8.4	0.8	NS
Grazing bout duration (min bout^{-1})	81.8	74.6	10.83	NS
Bite rate (bites min^{-1})	66.4	68.3	1.71	NS
Total bites (n d^{-1})	30,233	29,803	1,094.9	NS
Grazing mastications (n d^{-1})	8,195	9,837	1,010.8	NS
Ruminating time (min d^{-1})	416	409	20.2	NS
Ruminating bouts (n d^{-1})	11.3	11.1	0.46	NS
Ruminating bout duration (min bout^{-1})	37.4	37.0	1.97	NS
Ruminating mastications (n d^{-1})	27,630	28,406	1,641.9	NS
Ruminating boli (n d^{-1})	426	450	21.2	NS

ruminating, respectively. While no differences were observed in the ruminating behaviour of beef cows of diverse genetic merit in this study, the same proportion of the day (75% of time spent grazing) was spent ruminating as observed by Fraser and Broom (1997). Cows in the current study had 5.5 and 7.4 more bites min^{-1} for high and low genetic merit cows, respectively, compared to the highest bite rate of 60.9 for Tarentaise-Simmental-Hereford cross beef cows observed by Funston *et al.* (1991). However, in spite of this greater bite rate, the cows in the current study spent two hours less grazing. The shorter grazing time and greater bite rate may be a reflection of the different grazing conditions between these two studies, i.e. extensive rangeland in Montana compared to the intensive permanent pasture-based system employed in the current study.

Conclusion

While the current study expanded the limited amount of data available on the grazing behaviour of lactating beef cows, results from this study indicated that no difference existed in grazing behaviour between beef cows of diverse genetic merit for the Replacement Index. Despite this, inclusion of grass dry matter intake and measures of production efficiency measured across multiple years could provide a more competent appraisal of the potential differences among beef cows of varying genetic merit for the Replacement Index.

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Combining cattle and sheep on pasture: how do farmers organise the sharing of grass resources?

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Abstract

The mixed grazing of cattle and sheep can optimise the use of diverse resources, enhance the quality and quantity of grass and reduce the susceptibility of a system to climatic fluctuations. This study aimed to explore how farmers manage grass resources grazed by two species. Our results highlight four styles of mixed cattle and sheep grazing that lie along a continuum from no link between the two species to a high level of integration in space and time. We show that the configuration of the land and the type of bovine production (dairy or beef) influence how mixed grazing is managed.

Keywords: mixed grazing, dairy or beef cattle, sheep

Introduction

As the feeding behaviours of cattle and sheep are complementary (D'Alexis *et al.*, 2014), the mixed grazing of these two species can optimise the use of diverse resources, enhance the quality and quantity of grass (Cuchillo *et al.,* 2017), and reduce the susceptibility of a system to climatic fluctuations. However, few studies have examined how farmers allocate grass resources between the two species during the grazing season (Cournut *et al.,* 2012). The aim of our study was to explore this question. We sought to describe and understand the different styles of implemented mixed cattle and sheep grazing. We assumed that some structural factors, such as land configuration, available workforce, size of herds and flocks, stocking rate and type of bovine production, could facilitate the management of mixed grazing.

Materials and methods

Surveys were carried out on 17 farms combining dairy cattle with sheep meat production (DM farms) located in Planèze de St-Flour, a middle mountain area and on 20 farms combining beef cattle with sheep meat production (BM farms) located in Bocage Bourbonnais, a plains area. The farms were selected to cover as diverse a range of systems as possible in terms of flock and herd size and number of farmers. Semi-structured interviews were conducted on the structure and operations of farms with a focus on grazing management practices and the reasons for these practices. We analysed the data collected in three steps. First, we built variables describing the integration in space and time of mixed grazing (Bell and Moore, 2012). We then identified styles of mixed grazing corresponding to specific combinations of these variables. Finally, the different styles of mixed grazing were described by the farm structural characteristics and the reasons underlying the grazing practices. Due to the limited number of farms in the sample, qualitative analyses were performed.

Results and discussion

The average farm agricultural area (FAA) was 159 hectares (ha). Grassland covered 84% of this area. The total livestock was, on average, 164 livestock units (LU). The size of flocks varied from 50 to 1,025 ewes, and the size of herds varied from 18 to 95 lactating cows and 19 to 230 suckler cows. The number of farmers per farm varied from one to four. The stocking rate varied from 0.7 to 2.2 LU ha^{-1} of grassland. The farms used grazing systems that were more or less extensive. The sheep and cattle grazed from April to November, but on most BM farms, sheep were kept outdoors on fields near the farmstead during the winter.

To describe the integration in space and time of mixed grazing, we built three variables based on the diversity of grazing management practices. The first considers two modes of sharing space. In the first mode, each species has its own separate grazing zone. In the second mode, farmers split the space into three zones: one zone was grazed by the two species together (successive or co-grazing), another zone was grazed by sheep alone, and the third zone by cattle alone. The second and third variables concern the temporal dimension of integration and describe the way the two species are temporally combined on the shared zone. The second variable was the degree to which successive grazing was used: on the same field, sheep grazed occasionally, frequently, or never after cattle. Successive grazing could take place during the same season or in distinct seasons (winter grazing) of the same year, or from one year to another. The third variable was the degree to which co-grazing was used, especially on large fields: cattle and sheep grazed or did not graze together.

The combination of these three variables allowed us to identify four styles of mixed grazing with different modes of spatial and temporal integration of cattle and sheep on the pasture (Table 1). These four styles were: separated grazing (Group I, ten farms), low integration (Group II, 13 farms), moderate integration (Group III, eight farms), high integration (Group IV, six farms). Table 1 also presents for each group the percentage of farms with fields grouped around the farmstead, the percentage of farms with beef or dairy cattle, the mean number of farmers per farm, the mean FAA, the mean grassland FAA^{-1}, the mean total livestock units, the mean stocking rate, the mean herd and flock size, and the mean ewe cow^{-1} ratio. We noticed that the farms with a style of mixed grazing characterised by high integration in time and space of the two species had grouped field patterns and produced bovine meat. The absence of DM farms in this style of mixed grazing could be explained by the need for lactating cows to graze near the milking parlour, but also by the higher feed requirements of lactating cows compared to beef cows and ewes, as has been previously described in specialised cattle farms (Garcia-Launay *et al.,* 2012). The styles of mixed grazing did not seem to be dependent on the other farm characteristics.

Table 1. Characteristics of the four groups of farms with different styles of mixed grazing.

Variables	Group I	Group II	Group III	Group IV
Styles of mixed grazing	separated	low integration	moderate integration	high integration
Two modes of sharing space	2 zones specific for each species	2 zones specific for each species	2 specific and 1 non specific	2 specific and 1 non specific
Degree of use of successive grazing	no	occasionally	frequently	frequently
Degree of use of co-grazing	no	no	no	yes
% farms with grouped area[1]	30	61	62	100
% of farms with beef or dairy cattle[1]	dairy: 50 beef: 50	dairy: 61 beef: 38	dairy: 50 beef: 50	beef: 100
Number of farmers per farm (mean)	1.9	1.7	2.2	1.8
Farm agricultural area (FAA; ha; mean)	156	152	153	187
Grassland FAA^{-1} (%, mean)	84	83	85	87
Total livestock unit (LU; mean)	176	150	149	195
Stocking rate (LU ha^{-1} of grassland; mean)	1.26	1.14	1.17	1.17
Number of cows (mean)	89	61	76	83
Number of ewes (mean)	292	340	208	289
Ratio ewes cow^{-1} (mean)	5	9	3	6

[1] Percentage of farms per total number of farms present in each group.

According to some farmers, mixed grazing allowed the removal of grass refusals left by cattle and it improved grass growth. On a few farms, some hayfields were grazed by cattle in spring for topping and then by sheep in autumn. The use of mixed grazing was justified by some farmers as a way to limit waste. No farmers mentioned mixed grazing as a means to limit parasites, in contrast with findings from previous studies (d'Alexis *et al.,* 2014). Some farmers did not use mixed grazing, and especially co-grazing, for several reasons, such as the complexity of mixed grazing management, the need to have similar fences for two species and the risk of disease transmission between the species. The absence of mixed grazing could also be explained by the location of the sheep and cattle buildings and by the necessity to adapt the plots to the animals' requirement (feed and monitoring). Some farmers assigned poor plots (wetland, slope, low productivity, distant or lowly accessible) to sheep because they deemed sheep's requirements less important than those of cattle. Conversely, other farmers attributed highly productive plots to sheep.

Conclusion

Our results highlight different styles of mixed grazing, expressing a gradient in the integration in space and time of the two species on pastures. These different styles were influenced by the space configuration and the bovine production system, but do not seem to be linked to other structural characteristics such as the stocking rate, the workforce, or the ratio of ewes to cows. However, further studies should examine more precisely the role of labour in farmers' decision-making.

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An agro-ecological dairy cattle system to allow all year round grazing

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Abstract

In order to face the new challenges of dairy farming in north-west Europe, an innovative dairy system (90 ha, 72 cows, Lusignan, France) was redesigned to be resilient to climate change, while saving water and fossil fuel resources and contributing to sustainable agriculture. This system relies on the grazing of diversified forage resources and on an adapted cattle breeding system. The herd reproduction is based on two calving periods centred on spring and autumn. The age of heifers at first calving is reduced to 24 months, and the lactation length is extended to 16 months. A three-way crossing of dairy breeds (Holstein, Scandinavian Red, Jersey) was implemented to have more robust cows, with good reproduction capacity and well adapted to grazing. Grazed forage did not yet succeed in reaching 100% of the dairy herd feed in spring and 25% in winter, but was close or higher than the objective of 50% in summer and autumn, thanks to the grazing of various forage resources.

Keywords: mixed crop-dairy system, grazing, diversity, climate change, agroecology

Introduction

Dairy farming in north-west Europe has new issues to face: it has to be resilient to climate change, while saving water and fossil fuel resources and contributing to sustainable agriculture. To address these challenges, an innovative dairy cattle system (90 ha, 72 cows), called OasYs, was redesigned with an agroecological approach, by giving priority to grazing. Agroecology is grounded in the stimulation and valorisation of natural processes to reduce inputs and pollution in agroecosystems (Dumont *et al.*, 2014). Grazing is an energy- and water- saving management mode, which could reconcile economic and environmental performances (Peyraud *et al.*, 2010). It is also generally beneficial to animal welfare (Arnott *et al.*, 2017). However, the quantity and quality of grazed forage are highly dependent on climatic conditions. Climate change will enhance the frequency of extreme weather events, such as drought (IPCC, 2013), and will increase the overall variability of grassland production and availability (Dumont *et al.*, 2014). We hypothesise that a greater diversity of the dairy system's components and of their functions will both improve the resilience of the overall system against climatic hazards and permit high production levels and environmental performance. This paper presents the first results of the livestock breeding strategy and the forage resources used to allow all year round grazing.

Materials and methods

An agroecological dairy system has been implemented since June 2013 on an INRA facility located in Lusignan (Vienne, France), south of Brittany, in an area already affected by summer droughts. The herd reproduction is based on two calving periods centred on spring and autumn, to better link cattle needs with the growth of grasslands and also to overcome climatic hazards which could occur at one period. The age of heifers at first calving is reduced to 24 months, and the lactation length is extended to 16 months, to limit the non-productive period during cow lifetime and the associated negative environmental impacts. A three-breed rotational crossing of dairy breeds (Holstein, Scandinavian Red, and Jersey) is implemented to have robust cows with good reproduction capacity, which are well adapted to grazing and to forage resources of contrasting quality.

Cattle feeding relies on the grazing of diversified forage resources, with the objective to allow grazed forage resources to meet 100% of the dairy herd feed requirements in spring (meteorological season), 50% in summer and autumn and 25% in winter. Five-year grazed grasslands represent the heart of the forage system (36 ha of the 48 ha potentially grazable). They are diversified regarding their species, cultivars and age to provide grazeable forage resources in a wide range of climatic conditions (Novak *et al.*, 2016a). Short duration (six months to two years) grasslands provide fast- growing grass but of lower persistence (e.g. Italian ryegrass, Crimson clover, chicory). Annual crops (millet-forage sorghum with clovers, rape, fodder radish, fodder beet) are implemented to address the shortage of grass generally observed in summer, autumn and winter. We also use dual purpose crops (grain sorghum or cereal-legume mixtures) which can either be grazed or harvested (or both), depending on the amount of grass and conserved forage stores, to better adapt to climatic conditions. Legume-rich pastures may also be stockpiled from late spring to be grazed in summer. Finally, trees and shrubs have been planted in 2014 to provide browsed fodder in summer and autumn but also to shelter cattle and to improve the efficient use of natural resources (Novak *et al.*, 2016b).

Results and discussion

The new livestock breeding strategy initiated in June 2013 shows good progress (Table 1): four years after its start-up, calvings are nearly equally distributed between spring and autumn, and calving intervals level off at around 18 months (i.e. 548 days). As expected, three-breed crossbreeding takes more time to be effective: in 2017, the dairy herd was composed of 37% of Holstein and 63% of Holstein × Scandinavian Red or Holstein × Jersey crossbred cows. The amount of milk delivered decreased from 8,565 litres per cow in 2013 to 7,076 litres per cow in 2016, mainly as a result of the decrease in the amount of concentrates (from 127 g per litre of milk in 2013 to 74 g per litre of milk in 2016) and also as a result of crossbreeding. In the same period of time, the fat content of delivered milk increased from 39.7 to 41.7 g kg^{-1}.

From 2013 to 2016, five-year old grasslands provided 58 to 100% of the forage grazed by dairy cows, depending on the season (Figure 1). The objective to meet 100% of the dairy herd feed requirements with grazed forage in spring was not achieved, in spite of the grazing of cereal-legume mixtures and short duration grasslands. An earlier topping of grasslands could help to improve these results. On the contrary, the objective of 50% of grazing in summer was largely exceeded thanks to some grassland species (e.g. chicory, tall fescue) and annual crops (mainly cereal-legume mixtures and millet-sorghum). In autumn, grazing was close to 50% of the dairy herd feed, except in 2016, because the dry weather in summer and autumn did not allow sowing of the intended annual crops and sufficient regrowth of grasslands. Trees

Table 1. Results of the implementation of the new livestock breeding strategy which began in June 2013.

		2013	2014	2015	2016	2017
Calving distribution (% of cows)	spring	0	36	37	64	47
	autumn	100	64	63	36	53
Calving interval (days)		406	508	609	575	554
Crossbred cows in the dairy herd (%)[1]	H × R	0	0	0	10	25
	H × J	0	0	0	21	38
Age at first calving (months)		26.5	26.6	28.5	27.3	26.6

[1] H=Holstein, J=Jersey, R=Scandinavian Red.

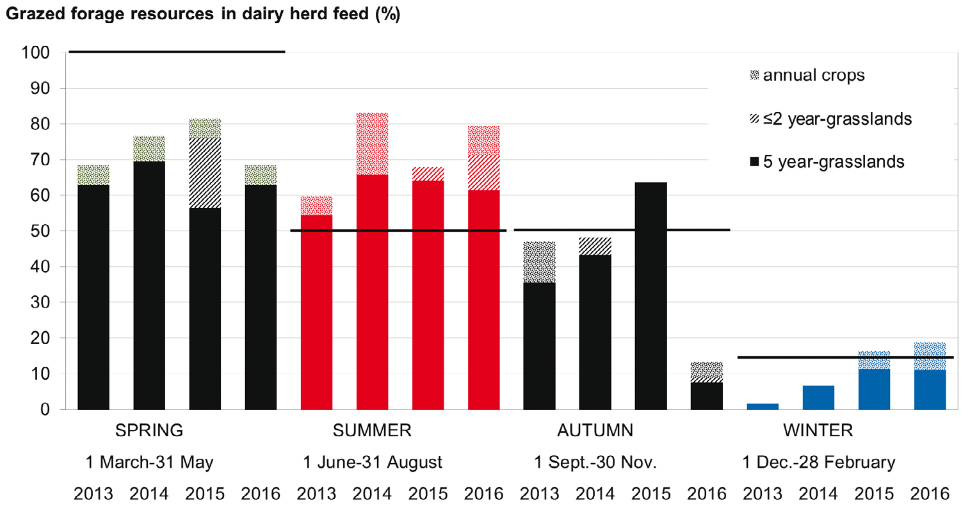

Figure 1. Part of grazed forage resources in dairy herd feed according to meteorological season, from spring 2013 to winter 2016 - 2017. The proportion of grazing in herd feed was estimated using the duration of grazing in each month. The horizontal bar indicates the target set for each season.

and shrubs were too recently planted to be browsed in summer or autumn. In winter, grazing represented less than 25% despite the use of fodder beet which represented up to 38% of the grazed forage.

Conclusion

This agroecological system experiment, through grazing, allowed the provision of most of the feed of the dairy herd in spring and summer and a large part in autumn. Grazed forage resources should increase in the following years with the full establishment of the system, leading to the browsing of fodder trees and shrubs and to crossbred cows more adapted to the system. We also intend to assess new grass and crop species and management practices so as to continue to extend the grazing period.

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Reproductive efficiency, body condition score and survival of dairy cows of divergent genetic merit

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Abstract

Reproductive efficiency was evaluated in two genotypes of Holstein-Friesian over four years. In each year, 90 cows representative of the top 1% (ELITE) and 45 cows representative of the mean nationally (NatAv) based on the Irish Economic Breeding Index (EBI) were evaluated. Cows were spring-calved and managed under three contrasting seasonal pasture-based feeding treatments. Reproductive efficiency indicators included the proportion of cows submitted in the first 24 days of the breeding season (SR24), proportion of cows pregnant to first service (PREG1), proportion of cows pregnant in the first six weeks of the breeding season (PREG6W) and proportion of cows pregnant after the 12 week breeding season (PREG12W), with pregnancy variables based on ultrasonic imaging at day 150 post commencement of breeding. Significantly higher SR24 ($P = 0.05$), PREG6W ($P < 0.01$) and PREG12W ($P < 0.001$) rates were observed with ELITE compared to NatAv cows. Body condition score (BCS) at all stages of lactation was higher ($P < 0.001$) with ELITE cows. Survival analysis confirmed higher survival rate to the end of fourth lactation for ELITE cows (0.60) compared with NatAv (0.40). Results indicate superior reproductive efficiency, body condition and survival is achieved through selection for high EBI.

Keywords: Economic Breeding Index, reproductive efficiency, body condition score

Introduction

The biological and financial efficiency of milk production in predominantly grazing systems, such as those practiced in Ireland, is uniquely dependant on a seasonal production model (Coffey *et al.*, 2016). Therefore, mutual compatibility between the cow and system is important (Buckley, 2005). Calving is aligned with the initiation of the grass growing season in early spring to ensure a long lactation at pasture (February to November), thus, the system is highly dependent on achieving a high pregnancy rate within a short-time interval following the start of breeding (Pryce, 2007). The optimum cow for pasture-based systems can only be identified by combining all traits of economic significance in a weighted index of economic merit and choosing sires at the top of this index (Horan *et al.*, 2005). Since 2001, trait emphasis in dairy cattle breeding in Ireland has shifted orientation from a milk production based index, the Relative Breeding Index, to a profit-based Economic Breeding Index (EBI) (Veerkamp *et al.*, 2002) to identify appropriate genetics for Irish grazing systems. The objective of this paper is to compare differences in reproductive efficiency, body condition score (BCS) and survival of dairy cows of divergent genetic merit based on EBI.

Materials and methods

A four year study to compare two distinct genotypes of Holstein-Friesian took place on the Dairygold Research Farm (Teagasc, Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland; 52°09' N; 8°16' W) from January 2013 through December 2016. In each year, 90 cows representative of the top 1% of the Irish national population of Holstein-Friesian dairy females (ELITE), ranked EBI, and 45 cows, representative of national average EBI females (NatAv) were evaluated. A total of 178 individual ELITE cows and 96 individual NatAv cows contributed data over the four year period. Mean calving date was February 15 (±16 d) and 18 (±18 d) for the ELITE and NatAv cows, respectively.

Genotypes were balanced for parity and calving date each year. In year 1 all animals were primiparous and by year 4 20% parity 1, 20% parity 2, 27% parity 3 and 33% parity 4 animals were present in each genotype. Mean EBI value of the ELITE and NatAv groups was €154 (milk sub-index (SI) €37, fertility SI €80) and €51 (milk SI €17, fertility SI €13), respectively (ICBF, May 2017). In mid-March each year, cows within each EBI group were randomly assigned to one of the three experimental treatments based on parity, calving date and pre-experimental yield of milk solids and milk composition (mean of two weeks). Reproductive efficiency indicators investigated included the proportion of cows submitted in the first 24 days of the breeding season (SR24), proportion of cows pregnant to first service (PREG1), proportion of cows pregnant in the first six weeks of the breeding season (PREG6W) and proportion of cows pregnant after the 12 week breeding season (PREG12W), with pregnancy variables based on ultrasonic imaging at day 150 post commencement of breeding. Cow BCS was recorded every three to four weeks by the same experienced classifier on a 1 to 5 scale (1 = emaciated, 5 = extremely fat) with increments of 0.25 (Lowman *et al.,* 1976). Analysis of reproductive efficiency indicators and mean BCS was conducted using a repeated measures model in PROC GENMOD or PROC MIXED of SAS 9.4 (SAS Institute, 2017), respectively. Cow nested within genotype was included as a random effect and year was included as a repeated effect. Genotype, feeding treatment, year, calving day of year and parity were included as fixed effects. The interactions of genotype, feeding treatment and parity were also investigated. Body condition score during lactation was categorised into 10 lactation stages; weeks 2 to 4, 5 to 8, 9 to 12, 13 to 16, 17 to 20, 21 to 24, 25 to 28, 29 to 32, 32 to 36, 37 to 44. The linear model used for BCS analysis included the fixed effects of genotype, feeding treatment, year, calving day of year, parity and lactation stage and the interaction between genotype and lactation stage. The effect of genotype on cow survival was established using the Cox proportional hazards model by using PROC PHREG of SAS, where date of culling for infertility was defined as the date of drying off at the end of the lactation during which the cow failed to conceive. Kaplan-Meier survival functions were estimated for each genotype by using PROC LIFETEST in SAS.

Results and discussion

No genotype by feeding treatment interaction was observed for any of the traits investigated. The main effect of genotype on reproductive efficiency variables of interest and mean BCS over lactation are presented in Table 1. Significantly higher SR24 ($P = 0.05$), PREG6W ($P < 0.01$) and PREG12W ($P < 0.001$) rates were observed with ELITE (92, 60, 73 and 92%, respectively), compared to NatAv cows (86, 46, 58 and 81%, respectively). Body condition score at all stages of lactation was higher ($P < 0.001$) in ELITE compared with NA cows (mean BCS 2.92 vs 2.74), and differences in BCS were maintained throughout lactation.

Survival analysis indicates mean distribution of survival to 1,380 days post first calving (equivalent to end of fourth lactation) was 0.60 and 0.40 for the ELITE and NatAv cows, respectively. The greater reproductive efficiency of ELITE cows relative to NatAv cows in the present study indicates greater compatibility of animals selected for high EBI with pasture-based milk production systems. Results observed reaffirm the contribution of genetic merit for fertility to reproductive performance and are

Table1. Effect of genotype on reproductive efficiency and mean body condition score.

	ELITE	SEM	NatAv	SEM	*P*-value
24 day submission rate	0.92	-	0.86	-	*
Pregnancy rate to first service	0.60	-	0.46	-	**
6 week in-calf rate	0.73	-	0.58	-	**
12 week in-calf rate	0.92	-	0.81	-	***
Mean body condition score (1-5)	2.92	0.05	2.74	0.06	***

consistent with the findings of Coleman *et al*. (2009) where genotypes of contrasting origin displayed differing reproductive performance, and Cummins *et al*. (2012), where cows of higher genetic merit for fertility exhibited greater reproductive efficiency than cows of low genetic merit.

Conclusion

Selection of animals for high EBI is resulting in cows of superior reproductive efficiency and greater survivability, both key requirements for optimising milk production from grassland systems. The results from this controlled experiment also provide strong evidence that the use of an appropriately weighted selection index that places emphasis on traits of economic importance, will result in the attainment of animals capable of performing optimally within grassland milk production systems.

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The effect of Economic Breeding Index and feeding treatment on 305 d production and lactation profile

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Abstract

The objective of this four-year study was to compare the effect of genetic improvement using the Irish Economic Breeding Index (EBI), and pasture-based feeding treatment on 305 d milk yield (MY), milk solids (fat plus protein; MS) yield and MS lactation profile. Genotypes (G) comprising ELITE (top 1% based on EBI) and NatAv (national average EBI) were randomly allocated to one of three seasonal pasture-based feeding treatments (FT) by mid-March each year; Control (CTL), Low Grass Allowance (LGA), and High Concentrate (HC), with target post-grazing sward height of 4.5 - 5, 3.5 - 4 and 4.5 - 5 cm, and total concentrate allowance of 300, 300 and 1,200 kg per cow per lactation, respectively. The Wilmink exponential function was applied to weekly MY and MS yield. No significant G×FT interaction was observed for any of the production variables. Least square means for 305 d MY (5773 vs 6000 kg) was lower ($P < 0.001$), while least square means for 305 d MS yield (476 vs 468 kg) tended to be greater ($P = 0.09$) with ELITE cows. ELITE had a significantly greater lactation profile (intercept post calving; *a* parameter) for MS than NatAv but had a greater decline in MS yield from intercept to end of lactation.

Keywords: Economic Breeding Index, lactation, persistency

Introduction

Within pasture-based feed systems, pasture supply is limited and animals that can convert restricted volumes of pasture into greater volumes of milk solids without repercussions on functionality will maximise productivity (Coleman *et al.,* 2010). The export orientated market for Ireland's largely commodity-based product portfolio (Geary *et al.,* 2010) dictates a requirement amongst milk processors for high solids content milk. The EBI (Veerkamp *et al.,* 2000) was launched in Ireland in 2001 to identify genetically superior animals for profitability under Irish conditions. The production sub-index accounts for 32% of the EBI and selects for fat and protein yield, with a negative economic weighting on milk volume (www.icbf.com). Monitoring phenotypic performance of animals selected using EBI is prudent to ensure the continued suitability of EBI as a breeding objective for grassland milk production systems into the future. The objective of the present study was to compare the effect of selection using EBI, and pasture-based feeding treatment on 305 d milk yield (MY), MS yield and MS lactation profile.

Materials and methods

Two genotypes of Holstein-Friesian based on the Irish total merit index, the Economic Breeding Index (EBI), were evaluated across four years (2013-2016). In each year of the study, 90 cows representative of the top 1% (ELITE; mean EBI €154; milk sub-index (SI) €37, fertility SI €80) and 45 cows representative of the mean nationally (NatAv; mean EBI €51; milk SI €17, fertility SI €13; ICBF, May 2017) were evaluated. Ninety-nine individual sires were represented. Mean predicted transmitting ability (PTA) for milk, fat, and protein yield was -18, +7.2 and +4.2 kg in the ELITE, and +46, +4.1 and +2.5kg in the NatAv genotype (G), respectively. In year 1, all animals were primiparous and by year 4, 20% parity 1, 20% parity 2, 27% parity 3 and 33% parity 4 animals were present in each G. Mean calving date was February 15 (±16 d) and 18 (±18 d) for the ELITE and NatAv cows, respectively. By mid-March of each year, cows within each G were randomly assigned to one of the three feeding treatments (FT) based on

EBI, parity, calving date and pre-experimental yield of MS (mean of two weeks). The CTL, LGA and HC treatments had a target post-grazing residual sward height of 4.5 - 5, 3.5 - 4, and 4.5 - 5 cm, and a total concentrate allowance of 300, 300 and 1200 kg per cow per lactation, respectively. The experimental area was a permanent grassland site containing greater than 80% perennial ryegrass (*Lolium perenne*). Cows were milked twice daily at 07:00 and at 15:30. Weekly milk production was established from daily recording (morning and evening) while milk fat and protein concentrations were determined weekly from successive p.m. and a.m. milk samples. A total of 541 lactation records were available, involving 274 animals over the four year period. The Wilmink (1987) exponential model based on a non-linear parametric curve was fitted to weekly measurements of milk and MS yield:

$$y_t = a + be^{-0.05t} + ct$$

In this model a, b and c are parameters to be estimated and relate to the intercept, incline and decline parameter, respectively, while y_t represents the milk production at day t of lactation. Total 305 d MY and MS yield were generated from the Wilmink function. A mixed model analysis using PROC MIXED (SAS Institute, 2017) was performed on 305 d MY and MS yield, and on the three parameters derived from the Wilmink function. Calving to conception interval was classified into intervals of 20 days. Genotype, FT, calving day of year, calving to conception interval and parity were included as fixed effects. Cow nested within G was included as a random effect while year was included as a repeated effect. Interactions between G, feeding treatment and parity were also investigated.

Results and discussion

The mean *R*-square for the fit of the Wilmink function to MY and MS was 0.79 and 0.61, respectively. No interactions were observed for 305 d MY or 305 d MS (Table 1). Total 305 d MY from the Wilmink function was lower with ELITE compared with NatAv cows. Total 305 d MY was greatest in cows on HC and lowest in cows on LGA. Least square means for MS yield tended to be greater in ELITE cows (+8 kg; $P = 0.09$). Total 305 d MS yield was greatest in cows on HC and lowest in cows on LGA. The shape of the lactation curve for MS yield differed with G and FT (Figure 1). The ELITE cows had a greater MS lactation profile (*a* parameter), but exhibited reduced persistency for MS yield (*c* parameter) compared with NatAv cows. Cows on HC had a greater MS lactation profile, while cows on the LGA had a lower MS lactation profile relative to cows on CTL (Table 1). A greater incline phase (*b* parameter) and reduced decline phase (*c* parameter) was achieved by cows on HC, while a similar incline phase and greater decline phase was observed in cows on LGA, relative to cows on CTL. Parity structure and calving date were maintained similar for each treatment group and calving to conception interval was included

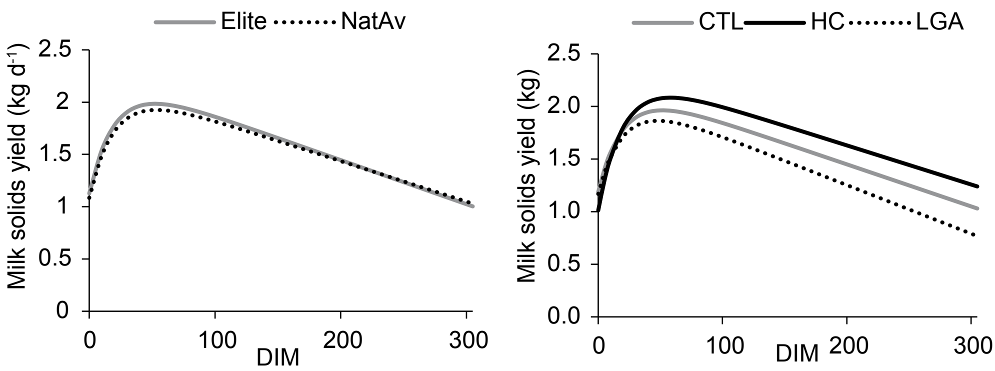

Figure 1. Effect of genotype (left) and effect of feeding treatment (right) on MS lactation profile.

Table 1. Effect of genotype and feeding treatment on 305 day milk and MS yield and MS lactation profile.

Item		Genotype			Feeding treatment				Significance		
		Elite	NatAv	SEM	LGA	CTL	HC	SEM	G	F	G×F
Milk (kg)		5,773[a]	6,000[b]	54.3	5,444[a]	5,735[b]	6,480[c]	54.6	***	***	ns
MS (kg)		476[a]	468[a]	3.6	436[a]	461[b]	518[c]	3.7	0.09	**	ns
Wilmink function parameters											
MS (kg)	*a*	2.30[a]	2.21[b]	0.03	2.18[a]	2.25[a]	2.37[b]	0.03	**	***	ns
	b	-1.16[a]	-1.13[a]	0.06	-1.01[a]	-1.06[a]	-1.36[b]	0.07	ns	***	ns
	c ($\times 10^{-3}$)	-4.26[a]	-3.86[b]	0.10	4.62[a]	4.00[b]	3.72[c]	0.12	***	***	ns

in the statistical model. The results of the current study, therefore, are independent of fertility differences presented by O'Sullivan *et al.* (2018).

Conclusion

The data from the present study show that selection using the EBI results in a tendency for increased 305 d MS production. ELITE cows had a lower volume of milk, however, this is economically more favourable. Results also suggest that increasing plane of nutrition (rising from LGA to CTL to HC) results in cows achieving a higher MS lactation profile and increased persistency of lactation.

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Effects of feeding strategy on fertility and performance in dairy cows with differing genetic merit

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Abstract

Holstein Friesian cows, ranked for genetic merit using Ireland's economic breeding index (EBI), were categorised to represent the top 1% (ELITE; n = 87), and the national average (NA; n = 45 cows). Three early lactation pasture feeding treatments: (1) control (C); (2) low grass allowance (LGA); and (3) a high concentrate (HC) were evaluated. Both ELITE and NA cows in the HC treatment had a smaller change in body condition score (BCS) compared to cows in C or LGA treatments groups. The ELITE cows had a higher submission rate after 24 days (SR24) of breeding (0.98 vs 0.89; $P < 0.01$) compared to NA cows. Six week in-calf rate for NA and ELITE cows was 54 and 77%, respectively ($P < 0.01$). Twelve week in-calf rate for NA and ELITE cows was 78 and 93%, respectively ($P < 0.01$). National average cows in the LGA treatment had a lower 12 week in-calf rate compared to cows in the HC treatment (60 vs 93%; $P < 0.01$). There was no difference ($P > 0.05$) in 6 week or 12 week in-calf rate for ELITE cows in any treatment group. Findings indicate that contrasting feeding strategies in early lactation impact on BCS and fertility parameters.

Keywords: genetic merit, fertility, nutrition, dairy cows

Introduction

It has been previously demonstrated that selection on the basis of genetic merit for fertility had a positive impact on reproductive efficiency (Cummins *et al.*, 2012). Nutrition influences reproductive performance in cattle through its concurrent and carryover effects on reproductive processes such as oocyte development, ovulation, fertilisation and embryo development. Feed fluctuations can be symptomatic in seasonal calving pasture-based dairy systems. Therefore, the objective of this study was to investigate if there was an interaction between early lactation feeding management and genetic merit on important fertility and performance parameters such as submission rate at 24 days of breeding (SR24), six week in-calf rate, 12 week in-calf rate and body condition score (BCS) change in early lactation in Holstein Friesian dairy cows.

Materials and methods

One hundred and thirty two spring calving Holstein-Friesian cows (n = 132), ranked for genetic merit (G) using Irelands economic breeding index (EBI; Irish Cattle Breeding Federation, May 2017), were categorised into those representing the top 1% (ELITE - mean EBI €169; n = 87), and the national mean genetic merit (NA – mean EBI €66; n = 45 cows). Mean calving date for all cows on the experiment was 17 February (range 16 January – 16 April). Cows were assigned to feeding treatments within genotype on the basis of parity and calving date. Three contrasting early lactation pasture feeding treatments (FT): (1) control (C); (2) low grass allowance (LGA); and (3) a high concentrate (HC) treatment were implemented during February through April 2017. Concentrate, 3 kg cow^{-1}day^{-1}, was offered to C and LGA cows from calving for a period of 12 weeks to supplement pasture availability, whilst 7 kgcow^{-1}day^{-1} concentrate was offered to HC cows in the same time period. Thereafter, and throughout the breeding season, all cows were managed similarly (4.5 cm post grazing residual and no concentrate supplementation).

Target post grazing residual height was 4.5 cm for both C and HC treatments compared with 3.5 cm for the LGA group. All cows were weighed weekly and condition scored fortnightly before and after calving. Body condition score was measured on a scale of 1 - 5 (Lowman *et al.*, 1976). The change in BCS was calculated between calving (February) and the end of April.

The breeding season commenced in late April and lasted for 12 weeks. Submission rate (SR24) was determined from the number of cows bred in the first 24 days of the breeding season. Six week in-calf rate was the proportion of cows pregnant after 42 days of the breeding season. Twelve week in-calf rate was determined at least 60 days after the end of breeding. All statistical analyses were carried out using procedures (PROC GLM and PROC GENMOD) of Statistical Analysis Systems (SAS version 9.4; SAS Institute Inc., Cary NC, USA 2004). Terms for parity, days in milk, G, FT and G×FT interactions were included in the model. Findings outlined here are from year one of a three year study.

Results and discussion

Mean ± sem post grazing residuals were 3.6 ± 0.07 cm, 4.5 ± 0.09 cm and 4.5 ± 0.09 cm for LGA, HC and C treatments, respectively. Mean pre-calving BCS was 3.33 ± 0.02 and 3.20 ± 0.03 for ELITE and NA cows, respectively ($P < 0.001$). The effects of G and FT on BCS and fertility parameters are outlined in Table 1. Mean six week in-calf rate for NA and ELITE cows was 0.54 and 0.77, respectively ($P < 0.01$). Mean 12 week in-calf rate for NA and ELITE cows was 0.78 and 0.93, respectively ($P < 0.01$). The ELITE cows had a significantly higher submission rate after 24 days of the breeding season (0.98 vs 0. 89; $P < 0.01$) in comparison to NA cows.

Teagasc's Next Generation dairy herd was established in 2012 to validate the hypothesis that genetic selection through the use of EBI will increase productivity under intensive pasture-based systems. The findings from initial experimental work indicated significant differences for six week (70 vs 50%) and 12 week (90 vs 81%) in-calf rate between ELITE and NA cows (O'Sullivan *et al.*, 2016). Overall, the differences in BCS and fertility performance between the two genotypes (ELITE vs NA) in this study are similar to the findings from initial experiments with the herd. Although there was no G×FT interaction for any of the outcome variables measured, the findings of this study indicate that contrasting feeding strategies in early lactation may have an impact on BCS and important fertility parameters in Holstein Friesian dairy cows.

Table 1. The effect of genotype (G)[1] of Holstein-Friesian and feeding system (F)[2] on body condition score (BCS) and fertility parameters in dairy cows of differing genetic merit.

	ELITE			NA			Sig.[5]		
	C	HC	LGA	C	HC	LGA	G	F	G×F
BCS – Pre calving	3.35 (0.04)	3.32 (0.04)	3.34 (0.04)	3.20 (0.05)	3.20 (0.05)	3.20 (0.05)	***	ns	ns
Δ BCS[3]	-0.44 (0.04)	-0.26 (0.04)	-0.49 (0.04)	-0.54 (0.06)	-0.18 (0.06)	-0.47 (0.06)	ns	***	ns
SR24[4]	0.95	0.99	1.00	0.87	0.87	0.94	*	ns	ns
6-week in-calf	0.71	0.74	0.87	0.58	0.62	0.41	0.08	ns	ns
12-week in-calf	0.96	0.93	0.90	0.79	0.93	0.60	**	*	0.09

[1] Genotype: ELITE (Top 1%) and national average (NA) based on Ireland's economic breeding index.

[2] Feeding systems: C = Control; HC = High concentrate and LGA = Low Grass Allowance.

[3] Δ BCS = BCS at end of April – Pre calving BCS.

[4] SR24 = Submission rate at 24 days of breeding.

[5] Sig. * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$ and ns = non-significant.

Conclusion

Although these are preliminary results, there are indications that contrasting feeding strategies at pasture in early lactation had an impact on body condition score and important reproductive performance parameters such as SR24, six week and 12 week in-calf rates in Holstein Friesian dairy cows.

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Finishing late-maturing suckler steers and bulls from pasture: effect of concentrate supplementation

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Abstract

Performance of late-maturing breed sired spring-born suckler bulls and steers finished at 19 months of age at pasture, with or without concentrate supplementation, was evaluated. At the start of the grazing season, 60 yearling bulls and steers were assigned to a 2 (gender (G)) × 2 (finishing strategies (FS): grass only or grass + 3.2 kg concentrate dry matter (DM) daily) factorial arrangement. Concentrates were introduced on day 97 and slaughter occurred on day 192. There were no G × FS interactions. Supplementation decreased estimated herbage intake by 0.57 and 0.43 kg DM kg^{-1} concentrate DM for bulls and steers, respectively. Bulls had a higher carcass weight (+44 kg), kill-out proportion (+14 g kg^{-1}) and carcass conformation score (+1.6 units, 1-15), a lower carcass fat score (7.9 vs 5.6, 1-15), darker muscle and less yellow subcutaneous fat than steers. Supplementation increased average daily live-weight gain (kg) during the supplementation phase (+0.36), and the grazing season (+0.23), carcass weight (+37 kg), kill-out proportion (+12 g kg^{-1}), carcass conformation score (+1.1 units), fat score (7.3 vs 6.3) and muscle redness. In conclusion, performance was superior for bulls and for supplemented animals; however, bull carcasses were only adequately finished (fat score, 6.0) when supplemented.

Keywords: beef cattle, carcass, concentrate supplementation, grazing

Introduction

Irish suckler beef production is largely based on late-maturing breed types and spring-calving pasture-based production systems (Drennan and McGee, 2009). Male cattle are mainly produced as steers although, recently, the proportion of bulls has increased substantially. Males produced as bulls are superior to comparable steers, for growth, feed conversion efficiency, carcass weight, conformation score and lean meat yield, but most published data derives from confined systems, often with high-concentrate inputs (O'Riordan *et al.*, 2011). In countries with a temperate climate, such as Ireland, grazed grass is the cheapest source of available nutrients and as feed provision is the largest variable cost on beef farms, finishing cattle from pasture rather than indoors can be economically attractive. The relative performance of late-maturing breed bulls and steers finished on grass-based systems is unclear. Therefore, this study aimed to evaluate the performance, growth, carcass characteristics and selected meat quality traits of late-maturing bulls and steers finished at pasture, with or without concentrates at 19 months of age.

Materials and methods

This study was conducted at Teagasc, Grange Research Centre in 2015. In total, 60 spring-born late-maturing (live weight 429 (s.d. 34.9 kg)), suckler-bred bulls were sourced from commercial beef suckler herds. Animals were blocked on sire breed and weight and half of them were castrated. During the indoor winter period, animals were offered grass silage to appetite, supplemented with 1.6 kg dry matter (DM) daily of one of two concentrate types. At the end of this period, animals were weighed on two consecutive days and within gender blocked by previous winter supplement type and live weight, and from within block, randomly assigned to a two (gender: bull or steer) × two (finishing strategies (FS): grass only (G0) or grass plus 3.2 kg DM barley-based concentrate offered once daily (GC)) factorial arrangement of treatments. Animals were turned out to pasture on the 7 April, rotationally grazing *Lolium perenne*-dominant swards for a total of 192 days. Concentrates were introduced 97 days post-turnout. Total grazing area was a single block of 13.2 hectares (ha), which was split into four equal farmlets (4.4 ha). Each farmlet consisted of 12 paddocks, which were divided into sub-paddocks to facilitate grassland management. Pre- and post-grazing sward heights (rising plate meter) and herbage mass above a 4 cm horizon (lawnmower cuts: four representative 5.0 × 0.55 m strips of grass per paddock) were recorded, estimated herbage DM intake (DMI) using the disappearance method was determined and representative samples of herbage were collected for DM and *in vitro* organic matter digestibility (OMD) determination as described by Lawrence *et al.* (2012). Animals were weighed at turnout to pasture, 48 hr post-turnout and pre-slaughter, and fortnightly throughout. *M. longissimus* (LM) and back fat depth were ultrasonically assessed at the beginning and end of the experiment. Animals were transported ~25 km to a commercial slaughter plant and slaughtered within 1 hr of arrival. Cold carcass weight was estimated as 0.98 of the hot carcass. Carcasses were graded mechanically for conformation and fat score according to the EU beef carcass classification scheme on a continuous 15-point scale. Ultimate pH and temperature of the LM was determined at 48 hr post-slaughter, and lightness (L), redness (a) and yellowness (b) of the LM (after 1 hr exposure) subcutaneous fat was measured and the ribs joint was dissected as described by Lenehan *et al.* (2017). Data were statistically analysed using the GLM procedure (PROC GLM) of Statistical Analysis Software (SAS). Animal was used as the experimental unit. The models contained fixed effects of gender and finishing strategy, their interactions and block. Differences between means were tested for significance using the PDIFF statement. Least square means are reported with standard errors.

Results and discussion

The mean OMD of the herbage offered during the grazing season was 771, 781, 781 and 767 g kg^{-1} for bulls G0, GC and steers G0 and GC, respectively. Corresponding mean pre-grazing sward heights were 8.8, 8.6, 9.2, 9.0 cm, and post-grazing sward heights were 4.5, 4.3, 4.1 and 4.7 cm. Corresponding pre-grazing herbage mass was 1,539, 1,448, 1,520, 1,599 kg DM ha^{-1}, and post-grazing was 506, 425, 395, 526 kg DM ha^{-1}. Estimated daily herbage DMI (kg $head^{-1}$) for bulls and steers over the first 97 days was 7.6 and 7.8, respectively. During the supplementation phase DMI of bulls offered G0 and GC was 10.0 and 8.2 kg and steers was 7.5 and 6.1 kg, respectively. Concentrate supplementation reduced herbage DMI by 0.57 and 0.43 kg kg^{-1} DM of concentrates for bulls and steers, respectively. There were no ($P > 0.05$) interactions between gender and finishing strategy for growth, body composition, carcass and meat quality traits (Table 1). Bulls were heavier than steers at turn-out to pasture ($P < 0.05$) and at slaughter ($P < 0.001$). Daily live-weight gain did not differ between the genders during the first half of the grazing season but was greater for bulls ($P < 0.001$) compared to steers during the supplementation phase and for the overall grazing season. Compared to steers, bulls had a lower ultrasonic fat depth at the ribs ($P < 0.001$), lumbar ($P < 0.01$) and rump ($P < 0.001$), pre-slaughter. Bulls had heavier carcasses ($P < 0.001$), greater kill-out proportion ($P < 0.01$), better carcass conformation ($P < 0.001$) and lower carcass fat scores ($P < 0.001$) than steers. Bulls had heavier ribs joint ($P < 0.001$) with a greater proportion of lean meat ($P < 0.001$), and a lower proportion of fat and bone compared to steers. Daily live-weight gain was greater for GC compared to G0 ($P < 0.001$) during the supplementation phase and the overall grazing season resulting in GC being heavier ($P < 0.001$) than G0 at slaughter. Compared to G0, GC had a greater ultrasonic LM depth ($P < 0.01$), and fat depth at the ribs, lumbar and rump ($P < 0.05$), pre-slaughter. GC had a heavier carcass ($P < 0.001$), greater kill-out proportion ($P < 0.01$), higher carcass conformation ($P < 0.01$) and fat ($P < 0.05$) scores than G0. Compared to G0, GC had a heavier ribs joint ($P < 0.001$), with a greater fat proportion ($P < 0.01$) and a lower bone proportion. Ultimate muscle pH was higher for bulls than steers ($P < 0.001$) but ultimate temperature did not differ ($P > 0.05$) between genders. Subcutaneous fat and muscle lightness, yellowness ($P < 0.001$) and saturation ($P < 0.01$) were lower in bulls compared to steers. Ultimate muscle temperature was higher for GC compared to G0 ($P < 0.01$). GC had higher subcutaneous fat lightness, redness, saturation and hue values ($P < 0.05$), and greater muscle redness ($P < 0.05$) and saturation ($P < 0.01$) compared to G0.

Table 1. Effect of gender and finishing strategy at pasture (Grass only, G0; Grass + concentrate, GC) on growth and carcass traits of late-maturing breed suckler bulls and steers.

Gender (G)	**Bull**		**Steer**		**s.e.m.**	**Sig.**	
Finishing strategy (FS)	**G0**	**GC**	**G0**	**GC**		**G**	**FS**
Daily live weight gain (kg)							
Pre-supplementation	1.32	1.43	1.20	1.35	0.035	NS	**
Post-supplementation	1.13	1.52	0.81	1.14	0.034	***	***
Overall grazing season	1.24	1.48	0.98	1.28	0.028	***	***
Carcass weight (kg)	386	415	334	379	5.27	***	***
Slaughter weight (kg)	678	715	604	667	7.84	***	***
Kill-out proportion (g kg^{-1})	570	580	554	568	3.11	**	**
Carcass conformation (1-15)	9.2	10.1	7.5	8.8	0.22	***	**
Carcass fat score (1-15)	5.0	6.2	7.5	8.3	0.28	***	*

Conclusion

Performance was superior for bulls and supplemented animals; however, bull carcasses were only adequately finished (fat score, 6.0, scale 1-15) when supplemented. Gender and concentrate supplementation had relatively minor effects on muscle and subcutaneous fat colour.

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Grass-based suckler steer weanling-to-beef production systems: Effect of breed and slaughter age

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Abstract

Performance of early- (EM) and late-maturing (LM) breed sired spring-born suckler steers within grass-based production systems was evaluated. Weaned steers (n = 144) were assigned to a 2 (Breed: EM and LM) × 4 (Production system: Grass silage for winter 1, pasture for 182 d-slaughter age 20.7 months (G0-20); Grass silage for winter 1, pasture for 182 d, grass silage for winter 2-slaughter age 24.5 m (G0-24); Grass silage + 0.8 kg concentrate DM daily for winter 1, pasture for 182 d, grass silage + 3.2 kg concentrate DM daily for winter 2-slaughter age 24.5m (GC-24); Grass silage for winter 1, pasture for 182 d, grass silage for winter 2, pasture for 110 d – slaughter age 28.2 m (G0-28) factorial arrangement. There were no breed × production system interactions. Compared to EM, LM were lighter at slaughter (-18 kg) but had a heavier carcass (+13 kg), better carcass conformation (+1.9 units), and lower carcass fat (-2.1 units) score. Carcass weights were 288, 316, 368 and 389 kg for G0-20, G0-24, GC-24 and G0-28, respectively. Kill-out proportion and carcass conformation were lower for G0-20 and G0-24 than for GC-24 and G0-28. Carcass fatness was lowest for G0-20, intermediate for G0-24 and highest for GC-24 and G0-28. With the exception of LM G0-20, all treatments were adequately finished.

Keywords: beef cattle, grazing, production system

Introduction

Low profitability is the primary issue for beef farms in Ireland. As provision of animal feed is the largest variable cost on beef farms feed-cost savings will have a proportionately large impact on financial performance. Of the predominant feedstuffs available in countries with a temperate climate, grazed pasture is the cheapest, followed by grass silage, and supplementary concentrates is the most expensive (Finneran *et al.*, 2012). Irish suckler beef production is largely based on late-maturing breed types and pasture-based production systems (Drennan and McGee, 2009). Where weaned suckler steer progeny are taken through to slaughter, there is usually a post-weaning indoor ('store') feeding period, where animals are offered a restricted-energy diet based on grass silage and concentrates, followed by a 'second' grazing season exploiting compensatory growth (McGee *et al.*, 2014), and finally an indoor finishing period, where steers are offered grass silage and concentrates prior to slaughter at 24 months of age (Drennan and McGee, 2009). Developing beef production systems based on only high-nutritive value grass, either grazed or conserved, should improve farm profitability. However, a key challenge is 'finishing' late-maturing breed cattle on grass forage-only diets and achieving an adequate carcass fat score (fat score > 6.0, scale 1 to 15) is a primary market requirement. Breeds differ greatly in their propensity for fat deposition (Moloney and McGee, 2017), thus early-maturing beef breeds may be more suitable for grass-based finishing systems. Within this context, the objective of this study was to evaluate the performance, growth and carcass characteristics of suckler-bred early- and late-maturing steers on contrasting grass-forage weaning-to-beef production systems without concentrates.

Materials and methods

This study was conducted at Teagasc, Grange Research Centre between October 2015 and July 2017. In total, 72 spring-born early-maturing breed (EM - Aberdeen Angus and Hereford sired) (306 (s.d. 54.0) kg live weight) and 72 spring-born late-maturing breed (LM - Limousin sired) (319 (s.d. 57.5) kg) weaned suckler-bred bulls were sourced directly from commercial herds in Ireland. Four weeks post-arrival animals were castrated and accommodated in pens within concrete slatted-floor sheds. Subsequently, they were blocked by sire breed and live weight, and randomly assigned to a two (Breed type: EM and LM) × four (Production system (PS): (1) Grass silage (only) for the 'first' indoor winter followed by 182 days at pasture - slaughter age, 20.7 months (G0-20); (2) Grass silage for the 'first' winter, followed by 182 days at pasture, re-housed and offered grass silage for the 'second' winter – slaughter age, 24.5 months (G0-24); (3) Grass silage + 0.8 kg of a barley-based concentrate dry matter (DM) per head daily for the 'first' winter, followed by 182 days at pasture, re-housed and offered grass silage + 3.2 kg concentrate DM daily for the 'second' winter – slaughter age, 24.5 months (GC-24) ('control' system); and (4) Grass silage for the 'first' winter, followed by 182 days at pasture, re-housed and offered grass silage for the 'second' winter, followed by 110 days at pasture – slaughter age, 28.2 months (G0-28) factorial arrangement of treatments. Grass silage-only treatments received a mineral-vitamin supplement daily. Grass silage, from a *Lolium perenne*-dominant sward, was mowed with a rotary mower and wilted for 36 hr, before harvesting with a precision-chop harvester; the *in vitro* dry matter digestibility of the silage offered during the first and second winter was 741 g kg^{-1} and 757 g kg^{-1}, respectively. Turnout date to pasture at the end of the first winter was 20 April 2016 and the end of the second winter (G0-28) was 14 March 2017. At pasture, all animals rotationally grazed *Lolium perenne*-dominant swards in breed-specific, replicate groups of six per (sub)-paddock. Pre-grazing sward height (rising plate meter) and herbage mass (lawnmower cuts) was measured and representative samples of herbage were collected for DM and *in vitro* organic matter digestibility (OMD) determination as described by Lawrence *et al.* (2012). For all treatments, mean pre-grazing sward heights were 10.1 and 9.5 cm, and herbage mass was 2.069 and 1.777 kg DM ha^{-1}, for the second and third season, respectively; corresponding mean OMD of the herbage offered was 779 and 781 g kg^{-1} DM. Animals were weighed at turnout to pasture, 48-hr post-turnout and pre-slaughter, and regularly throughout. Animals were transported ~25 km to a commercial abattoir and slaughtered within 1 hr of arrival. Cold carcass weight was estimated as 0.98 of the hot carcass. Carcasses were graded mechanically for conformation and fat score according to the EU beef carcass classification scheme on a continuous 15-point scale. Data were statistically analysed using the GLM procedure of Statistical Analysis Software (SAS). Animal was used as the experimental unit. The statistical models contained fixed effects of breed type and production system, their interactions and block. Differences between means were tested for significance using the PDIFF statement. Least square means are reported with standard errors.

Results and discussion

There were no ($P > 0.05$) interactions between breed type and production system for growth, and carcass traits (Table 1). Average daily live weight gain (ADG) did not differ ($P > 0.05$) between breed types during the first winter or third grazing season but was lower for LM compared to EM during the second grazing season ($P < 0.001$) and indoor winter period ($P < 0.05$). During the first and second winter periods, ADG was higher ($P < 0.001$) for GC-24 than all other treatments, which did not differ from each other ($P > 0.05$). LM steers had heavier carcasses ($P < 0.05$), increased kill-out proportion ($P < 0.001$), better carcass conformation score ($P < 0.001$) and lower carcass fat scores ($P < 0.001$) than EM steers.

Slaughter weight and carcass weight differed between all production systems ($P < 0.001$), being lightest for G0-20, followed by G0-24, then GC-24 and heaviest for G0-28. Kill-out proportion and carcass conformation score did not differ ($P > 0.05$) between G0-20 and G0-24, and both were lower ($P > 0.001$) than GC-24 and G0-28, which did not differ ($P > 0.05$). Carcass fat score for GC-24 and G0-28 did not differ ($P > 0.05$), and were higher than G0-24, which, in turn, was higher than G0-20 ($P > 0.001$).

Table 1. Effect of breed type (BT) and production system (PS) on average daily live weight gain (ADG), slaughter weight and carcass traits of suckler-bred steers.[1]

Breed type	**Early-maturing**				**Late-maturing**				**s.e.m.**		**Sig.**	
Production system	**G0-20**	**G0-24**	**GC-24**	**G0-28**	**G0-20**	**G0-24**	**GC-24**	**G0-28**	**BT**	**PS**	**BT**	**PS**
ADG (kg)												
2nd grazing	0.87	0.91	0.80	0.80	0.80	0.70	0.70	0.66	0.021	0.026	***	ns
2nd winter	.	0.64	1.13	0.78	.	0.65	1.08	0.60	0.030	0.040	*	***
3rd grazing	.	.	.	1.57	.	.	.	1.57	0.055	0.055	ns	.
Slaughter wt. (kg)	528[a]	596[b]	663[c]	708[d]	527[a]	558[b]	649[c]	690[d]	7.2	10.1	ns	***
Carcass wt.(kg)	280[a]	314[b]	361[c]	381[d]	295[a]	319[b]	375[c]	397[d]	4.1	5.7	*	***
Kill-out proportion (g kg^{-1})	531[a]	527[a]	543[b]	538[b]	560[a]	569[a]	576[b]	576[b]	2.1	3.0	***	**
Conformation score, 1-15	5.8[a]	5.7[a]	6.9[b]	7.8[b]	7.5[a]	8.1[a]	8.9[b]	9.1[b]	0.17	0.24	***	***
Fat score, 1-15	6.1[a]	8.5[b]	9.9[c]	10.1[c]	4.1[a]	6.1[b]	8.0[c]	7.9[c]	0.19	0.26	***	***

[1] (G0-20) Grass silage first winter, 182 d at pasture - slaughter age, 20.7 mths; (G0-24) Grass silage first winter, 182 d at pasture, re-housed grass silage for second winter – slaughter age, 24.5 mths; (GC-24; control) Grass silage + 0.8 kg DM hd^{-1} day^{-1} concentrate first winter, 182 d at pasture, re-housed grass silage + 3.2 kg DM hd^{-1} day^{-1} concentrate for second winter – slaughter age, 24.5 mths; (G0-28) Grass silage first winter, 182 d at pasture, re-housed grass silage for the second winter, followed by 110 d at pasture – slaughter age, 28.2 mths

Conclusion

Carcasses of spring-born suckler-bred steers were adequately finished (fat score > 6.0, scale 1-15) from all production systems except LM G0-20; both EM and LM could be finished from solely pasture at ~ 28 months of age, but only EM was finished at ~20 months of age.

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Effect of production system on the health and performance of Holstein bulls during their first summer

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Abstract

Holstein bull beef production is commonly an intensive *ad libitum* concentrate indoor system. However, systems involving a grazing period potentially offer a lower cost of production. The objective of this trial was to identify if a grazing period could be included in bull beef production. A 2 (season) × 4 (production system) factorial design experiment involving 112 Holstein bulls was undertaken. Season differed by either autumn born or spring born. The four production systems differed during the summer with treatments including: (1) housed with *ad libitum* access to concentrates and silage (HA); (2) grazed with *ad libitum* access to concentrates (GA); (3) grazed with 2 kg day^{-1} concentrates (G2); and (4) grazed with no concentrates (G). Grass based treatments (GA, G2 and G) were rotationally grazed in seven day paddocks from 26 May 2017. Bulls were weighed fortnightly and health was monitored visually, with the effectiveness of rumen temperature boluses evaluated for identifying ill health.

Keywords: dairy-origin bull beef, concentrate supplementation, production system, grazing

Introduction

The ability for bulls to out-perform steers in terms of growth rate and feed efficiency (Steen, 1994) allows for increased efficiency in beef production systems. However, Holstein bull beef production in the UK and Ireland is predominantly an intensive indoor system, involving a high level of concentrate feeding (Allen and Kilkenny, 1984) and consequently, is subject to fluctuating concentrate prices and market volatility (Ashfield *et al.*, 2014). Profitability in a pasture-based dairy-origin beef system is determined by two main factors: carcase output per hectare and the proportion of grazed grass in the diet (Ashfield *et al.*, 2014). The inclusion of a grazing period during the first summer can help to reduce production costs. However, with bulls being characteristically leaner than steers (Steen, 1994); it is important that growth rates, carcase weight and fat class are not compromised. Thus, concentrate supplementation at grass during the growing period may be required to ensure bulls meet market specification at slaughter. The objective of this study was to compare the health and performance of bulls on four differing production systems to identify if a grazing period could be included in Holstein bull beef production and if concentrate supplementation at grass was required.

Materials and methods

A 2 (season (S)) × 4 (production system (PS)) factorial design experiment was undertaken at AFBI, Hillsborough. This involved 112 Holstein bulls spilt by season into either autumn born (AB) (191 ± 10.3 d initial age and 196 ± 10.5 kg initial live weight) or spring born (SB) (106 ± 6.0 d initial age and 106 ± 5.8 kg initial live weight). The four production systems differed during the summer with treatments including: (1) housed with *ad libitum* access to concentrates and silage (HA); (2) grazed with *ad libitum* access to concentrates (GA); (3) grazed with 2 kg day^{-1} concentrate supplementation (G2); and (4) grazed with no concentrate supplementation (G). Each treatment group consisted of 14 bulls, balanced for weight and age. The two HA treatment groups were housed on slatted accommodation with access to cubicles, while the SB HA bulls also had access to a straw bedded area until d72. From d73 all HA bulls were on slatted accommodation. The GA, G2 and G treatments were rotationally grazed in seven day paddocks from 26 May 2017. Bulls were offered fresh feed daily; grass silage (HA) was fed through a diet feeder and concentrates were group fed either in a trough (HA and G2) or creep feeder (GA). All AB bulls were housed on 24 August 2017 after 90 d at grass and SB bulls on 11 October 2017, following 138 d at grass. On d 90 HA bulls were moved to the finishing house. One AB G2 bull was removed from the trial on d 28 due to photosensitivity.

An 8 ha mature perennial ryegrass (*Lolium perenne)* pasture was divided into four equal blocks of 1.8 ha, the remaining 0.8 ha was used as roadways to access each grazing block. Each block was subdivided into three paddocks of 0.38 ha for AB bulls and three paddocks of 0.21 ha for SB bulls. Each of the six treatment groups at grass were assigned one paddock per block.

The concentrate consisted primarily of maize, rolled barley, US distillers and corn gluten at 20, 19.9, 19.8 and 14.9 g kg$^{-1,}$ respectively. The HA and GA bulls were gradually built up to *ad libitum* concentrates, at the same rate. Concentrates were split into two feeds daily from 3 kg and 4 kg supplementation for the SB and AB groups, respectively until *ad libitum* at d 28 for SB bulls and d 56 for AB bulls. The G2 bulls were fed 2 kg fresh weight from the beginning of the trial.

Bulls were weighed on two consecutive days immediately prior to the commencement of this trial, with the mean of these weights taken as the initial live weight. Thereafter, bulls were weighed fortnightly. Bulls were observed daily for ill health and reticulo-rumen temperature was monitored continually using an in-dwelling rumen temperature bolus in all SB bulls and 5 AB bulls in each of the four treatment groups. Bovine respiratory disease (BRD) and acidosis incidences were calculated as the percentage of bulls that exhibited clinical signs. Bovine respiratory disease was classified as a bull with a high temperature and at least one other clinical sign of BRD (e.g. nasal discharge, coughing, dullness or increased respiratory rate). Clinical signs of acidosis included dullness, weight loss and fluid faeces. Group dry matter intake (DMI) of silage and concentrates were recorded daily and refused feed was removed twice weekly, prior to fresh feed being offered. Pre- and post- grazing heights were measured using a Jenquip rising plate meter and the difference used to estimate DMI; total group DMI was divided by the number of bulls in each treatment group. Pre- and post-grazing grass samples were analysed weekly for chemical composition using NIRS. Silage and concentrate samples were dried at 85 °C for 48 hours to determine dry matter concentration. The chemical composition of silage and concentrates was determined using NIRS and a wet chemistry analysis, respectively. All results were analysed by ANOVA using Genstat, while housing weight was analysed, as an ANCOVA using start weight as a covariate.

Results and discussion

Concentrate DM, crude protein (CP) and metabolisable energy (ME) were 871 g kg^{-1}, 150 g kg DM^{-1}, 11.1 MJ kg DM^{-1}, respectively. Grass silage DM, CP and ME were 260 g kg^{-1}, 124 g kg DM^{-1} and 10.6 MJ kg DM^{-1}, respectively. Likewise grazed grass was 140 g kg^{-1}, 190 g kg DM^{-1} and 11.0 MJ kg DM^{-1}, respectively. The chemical composition of the pre- and post-grazed grass did not differ ($P > 0.05$) between treatments and thus, the results are not shown. The GA paddocks were either topped or grazed (once *ad libitum* was reached) by a batch of 30 spare cattle; operating a leader-follower system. Thus, regardless of the fact that *ad libitum* concentrate feeding dramatically reduced grass DMI, all bulls were turned into fresh re-growth accounting for the lack of difference observed.

Table 1 shows that grazed grass sustained growth rates of 0.9 kg d^{-1} for the AB bulls, however, it only sustained 0.64 kg d^{-1} for SB bulls. Supplementing bulls with 2 kg resulted in an additional ($P < 0.001$) 20.1 kg live weight for AB bulls and 26.7 kg for SB bulls. Final weight for GA and HA bulls was not statistically different for either AB or SB bulls. However, HA bulls had a lower ($P < 0.001$) concentrate and forage DMI. This would indicate that *ad libitum* feeding is more beneficial while bulls are housed; however, there was more concentrate wastage for GA bulls due to spillage around the creep feeder. In

Table 1. Effect of season (S) and production system (PS) on daily liveweight gain (DLWG), dry matter intake (DMI) and health of bulls during their first summer when housed with *ad libitum* access to concentrates and silage (HA); grazed with *ad libitum* access to concentrates (GA); grazed with 2 kg day^{-1} concentrate supplementation (G2) or grazed with no concentrate (G).

Season (S)	Autumn born						Spring born						S × PS
Production system (PS)	G	G2	GA	HA	SEM	Sig.	G	G2	GA	HA	SEM	Sig.	Sig.
Final weight (kg)	279.1^a	299.2^b	345.8^c	338.8^c	4.890	<0.001	194.2^a	222.9^b	278.0^c	289.4^c	7.545	<0.001	ns
Final age[1] (d)	283	274	281	285	10.35	ns	243	245	238	249	6.040	ns	ns
DLWG (kg d^{-1})	0.90^a	1.15^b	1.67^c	1.59^c	0.066	<0.001	0.64^a	0.84^b	1.24^c	1.33^c	0.055	<0.001	ns
Concentrate DMI (kgDM d^{-1})	0.00^a	1.57^b	6.81^d	5.20^c	0.253	<0.001	0.00^a	1.63^b	5.13^d	4.27^c	0.150	<0.001	<0.001
Estimated forage DMI (kgDM d^{-1})	6.21^d	4.96^c	3.69^b	1.90^a	0.077	<0.001	4.32^c	4.40^d	2.87^b	0.70^a	0.019	<0.001	<0.001
BRD incidence (%)	0.0	0.0	0.0	0.0	0.000	ns	0.0	0.0	7.1	0.0	3.570	ns	ns
Acidosis incidence (%)	0.0	0.0	7.1	0.0	3.570	ns	7.1^a	50.0^b	57.1^b	35.7^{ab}	12.33	<0.05	ns
Mortality rate (%)	0.0	0.0	0.0	0.0	0.000	ns	0.0	0.0	14.3	0.0	6.860	ns	ns

[1]Autumn born bulls were housed after 90 days at grass and spring born bulls were housed after 138 days at grass.

addition, GA post-grazing heights were suppressed due to bulls tramping grass, as opposed to eating it; thus, the actual DMI of the GA bulls may be lower than that estimated in Table 1.

Infectious disease incidence was low during this trial with only one mild case of BRD, thus there was no significant effect on health. However, nutritional disorders were an issue with acidosis incidence rates as high as 57.1% for GA SB bulls. Two SB GA bulls were euthanised during this trial. Although post-mortem results were inconclusive, clinical symptoms indicated acidosis was the likely cause of morbidity.

Conclusion

In conclusion, a grazed period could be included in the production system of AB bulls, with acceptable growth rates of 0.9 kg d^{-1} achievable from grass. However, 2 kg concentrate supplementation was required for SB bulls to achieve growth rates of 0.84 kg d^{-1}. Acidosis was an issue in SB bulls, limiting performance during the first summer.

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Effect of pre-grazing herbage mass on behavioural characteristics of dairy cows

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Abstract

The purpose of this study was to validate a new RumiWatch converter (C31) which differentiates prehension bites from mastication chews during eating. Furthermore, the study investigated the effects of a low (LHM, 589 kg DM ha^{-1}) and high (HHM, 2288 kg DM ha^{-1}) pre-grazing herbage mass (PGHM) at similar herbage allowances (HA, 22 kg DM $animal^{-1}$ d^{-1}) on bite mass, DM intake (DMI), number of prehension bites and milk production. The C31 was validated in comparison with the previous RumiWatch converter (C11), and additionally, with visual observations of behavioural characteristics. A total of 24 Holstein cows were allotted pairwise to one of the two treatments. On average, LHM cows produced more energy-corrected milk, had the same herbage DMI (hDMI) and similar prehension bite mass. The eating time was longer and the rumination time shorter for LHM cows compared to HHM cows. Besides prehension bites and mastication chews during eating, C11 and C31 performed similarly well in identifying the various behavioural characteristics. Compared to visual observation, C31 showed a mean absolute percentage error (MAPE) for prehension bites of 12%. Only a small part of the herbage intake variability could be explained by the number of prehension bites.

Keywords: pre-grazing herbage mass, behaviour, dairy cow, pasture, RumiWatch

Introduction

In many respects, knowledge of individual herbage dry matter intake (hDMI) of grazing dairy cows is essential. This knowledge helps monitor nutritional status, feed efficiency as well as pasture and livestock management. As a step to the long-term objective of estimating hDMI, based partly or completely on individual behavioural characteristics, the subsequent experiment was carried out. During grazing, dairy cows perform prehension bites and mastication chews. As only prehension bites serve for hDMI, it may be important for a more accurate intake estimation to record these separately (Laca and WallisDeVries, 2000). A recent evaluation software, called converter (C31), of the RumiWatch System (RWS) enabled the detection of every single jaw movement and the differentiation of eating chews in prehension bites and mastication chews. Using this software, it might be possible to describe grazing events of dairy cows more precisely and to estimate hDMI more accurately. The first objective was to validate the C31 in comparison to the previous RumiWatch converter (C11), and additionally, with direct visual observations. Further, the effects of two different pre-grazing herbage masses (PGHM) at the same targeted herbage allowance (HA) on bite mass, hDMI, number of prehension bites and milk production were investigated.

Materials and methods

The study was carried out at the Agroscope experimental farm in Posieux (Switzerland) in September 2015. The experiment lasted three wk, with a 14 d adaptation and a seven d measurement period. Twenty four Holstein and Red-Holstein cows were allotted pairwise to one of two treatments based on body weight, milk yield, days in milk and lactation number. Cows grazed 19 h d^{-1}, had free access to water and were not supplemented in the barn. The treatments consisted of two different PGHM: either 589 kg DM ha^{-1} for LHM or 2288 kg DM ha^{-1} for HHM, but with the same targeted HA of 22 kg DM cow^{-1} d^{-1} above 3.4 cm (Jenquip rising plate meter, Feilding, New Zealand). New paddocks were offered to both groups twice per day after each milking. Recordings and evaluations of the behavioural characteristics were completed using the RWS, the RW Halter (version 6.0, Itin & Hoch GmbH, Liestal, Switzerland) as well as the C11 (Converter 0.7.3.11, Itin & Hoch GmbH) and the C31 (Converter 0.7.3.31, Itin & Hoch GmbH). Milk yield was measured twice daily and milk composition was analysed on d 2, 4, and 6 during the measurement week. To estimate individual hDMI on pasture, the *n*-alkane double indicator method was used, as described by Heublein *et al.* (2017). The direct observation, reference method for the validation of C11 and C31, was done on d 1, 3 and 5 during the measurement week for each cow. One trained observer performed all 72 observation sequences, each of which lasted 10 minutes. To indicate the accuracy of C11 and C31 compared to direct observations, the mean absolute percentage error (MAPE) was calculated. A linear mixed model (Systat 13, Systat Software, Chicago, USA) with a fixed effect treatment (PGHM) and a random effect cow pair was used for the statistical analyses for milk production, intake and behaviour variables.

Results and discussion

Post-grazing sward heights were similar between treatments, 3.8 cm for HHM and 3.9 cm for LHM. The pasture swards were composed of different grasses 720 (standard deviation (SD) 41) g kg^{-1} fresh matter, legumes 260 (SD 44) g kg^{-1} and forbs 20 (SD 6) g kg^{-1}. During the measurement period, the nutritive value of herbage DM was 6.3 MJ net energy for lactation (NEL), 218 g acid detergent fibre (ADF), and 184 g crude protein (CP) for HHM. For LHM, values were 6.6 MJ NEL, 188 g ADF, and 240 g CP.

The MAPE between C31 and direct observation was 6% (C11: 6%) for eating time, 11% (C11: 10%) for eating chews, 12% for prehension bites, 52% for mastication chews head down, 68% for mastication chews head up, 2% (C11: 2%) for rumination time, 4% (C11: 4%) for rumination chews, 9% (C11: 9%) for bolus count and 10% (C11: 12%) for chews per bolus.

Cows grazing on LHM produced more milk (25.4 vs 22.7 kg d^{-1}; $P = 0.008$) and more energy corrected milk (26.6 vs 24.1 kg d^{-1}; $P = 0.003$) and showed a trend for greater milk protein content (36 vs 34 g kg^{-1}; $P = 0.06$) compared to HHM. No treatment effects were seen on the milk fat content (44 vs 46 g kg^{-1}; $P = 0.22$), lactose content (46 vs 46 g kg^{-1}; $P = 0.63$), hDMI (15.6 vs 15.0 kg d^{-1}; $P = 0.33$), prehension bite mass (0.49 vs 0.47 g DM bite^{-1}; $P = 0.55$) and hDMI rate (26 vs 27 g min^{-1}; $P = 0.22$). Cows grazing on LHM had a longer grazing time (617 vs 559 min d^{-1}; $P = 0.004$), a lower eating frequency (70 vs 76 min^{-1}; $P = 0.002$), ruminated less (297 vs 365 min d^{-1}; $P < 0.001$), performed fewer rumination chews (18,436 vs 23,625 chews d^{-1}; $P = 0.001$) and regurgitated fewer boluses (365 vs 441 boli d^{-1}; $P = 0.005$) compared to HHM cows. No differences were seen between the two treatments for the number of eating chews (42950 vs 42220 chews d^{-1}; $P = 0.60$) and prehension bites (32,366 vs 32,244 d^{-1}; $P = 0.95$) as well as for the number of chews per bolus (51 vs 54 bolus^{-1}; $P = 0.15$) during rumination.

The coefficient of determination between eating chews or prehension bites and hDMI for the different treatment were low (0.05 to 0.3).

For grazing cows, the C11 had been extensively validated (Rombach *et al.*, 2018). Since the C31 is a further development of the C11, it is not surprising that behavioural characteristics such as eating time, eating chews, rumination time, rumination chews, bolus counts and number of chews per bolus were recognised equally well by both converters. In contrast to C11, C31 is able to identify prehension bites and is similar in accuracy to an acoustic measurement tool (Laca and WallisDeVries, 2000). For grazing dairy cows, the determination of mastication chews head up and down made by C31 are prone to errors.

Contrasting results are found in the literature in relation to the effect of HM on hDMI, milk production and behaviour at the same HA. According to Pérez-Prieto and Delagarde (2012), this has largely to do with the sward height above which the HA is measured. For a better ease of comparison, realistic HA might be calculated from a level similar to the defoliation limit of dairy cows, as in our experiment. Eating time and average intake rate per day in strip-grazing or rotationally grazing systems also depend on sward characteristics for reasons others than pre-grazing state. These include, but are not limited to post-grazing sward height, tear strength of different strata and duration of grazing periods (Pérez-Prieto and Delagarde, 2012). An increased eating time for LHM cows and similar numbers of prehension bites per day as HHM cows might show that LHM cows needed more time to select herbage compared to HHM cows. The increased fibre content might be the reason for longer rumination duration (Welch and Smith, 1970), more rumination chews and boluses. Pérez-Prieto *et al*. (2013) also observed a considerable increase in rumination duration when cows grazed on swards with increased HM.

Average prehension bites or eating chews per day explained only about 20% of the variation of hDMI. Consequently, prehension bites or eating chews alone did not enable an accurate hDMI prediction.

Conclusion

The evaluation software C31 identifies prehension bites relatively well (MAPE = 12%), but the detection of mastication chews during eating is prone to errors. Under the given conditions, HM had no influence on the number of prehension bites, hDMI or herbage bite mass averaged per day. Finally, the number of prehension bites explained only a small part of hDMI variation.

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The possibility of renovation of pastures for horses using an undersowing method

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Abstract

Correct management is essential to maintain the productivity and value of pasture as well as provide the nutrients and location to breed healthy horses. In some situations, however, intensive management results in pasture degradation. The aim of this paper is to show the possibility of the undersowing method for pasture renovation. The field experiment was established in 2016 on a private horse farm located in central Poland. High stocking rate and very intensive management previously caused pasture degradation. Sward renovation was completed using the undersowing method; three different grass mixtures (A: *Lolium perenne, Festuca rubra, Poa pratensis;* B: *Lolium perenne;* C: *Lolium perenne, Lolium multiflorum, Festuca arudinacea*, *Festuca rubra*) were sown in four replicates using a randomised block system. During the vegetative period 2016/2017 three factors were measured: sward height, sod density and the proportion of particular groups of plants (grasses, legumes, herbs and weeds). The undersowing method was successful and showed that the seed mixtures differed individually in their renovation ability but the multi species seed which included *Lolium perenne*, *Festuca rubra* and *Poa pratensis* appeared best for renovation compared to other mixtures (better sod density and good botanical composition).

Keywords: botanical composition, grass-seed mixtures, horse, pasture renovation, undersowing

Introduction

Pasture is a cheap highly digestibility source of nutrients for all herbivorous animals. Horses graze *in-situ*, frequently moving to reduce the symptoms of unwarranted aggression (Berg *et al*., 2015).

Overly intensive pasture management due to excessive trampling, especially around watercourses, gates or shade trees, reduces the regenerative capacity of the pasture and limits its durability (Mayer and Coenen, 2009). This results in progressive degradation that is reducing the quality and value of the pastures (Longland, 2013).

The aim of this paper is to present the effects of undersowing as a method for pasture renovation. Three different seed mixtures were used for renovation in order to determine which one is most suitable for horse pastures in Poland.

Materials and methods

The field experiment was established in 2016 on a private horse farm, located 80 km east of Warsaw. During the experiment there were 27 horses (16 hot-blooded horses, 9 hucul horses and 2 ponies). Horses were taken to the paddocks every day, during the pasture season (from April to September). The grazing area was about 6.5 hectares. The field experiment took place in two locations which differed in moisture, paddock 1 (1.95 ha) was dry (P1), paddock 2 (0.97ha) was wet (P2).

Three grass mixtures were sown in four replications on each part of the pasture (P1 and P2). In total there were eight small plots 1 m^2. The grass mixtures differed in species composition and variety. Mixture A was prepared using three grass species (*Lolium perenne*, *Festuca rubra* and *Poa pratensis*), Mixture B consisted only of two varieties of *Lolium perenne* (Romance and Barminton) and mixture C was *Festuca arudinacea* and *Lolium multiflorum* and no *Poa pratensis.*

Before undersowing, plots were cultivated, to reduce the competitiveness of the old sod. A seeding rate of (30 gram m^{-2}) was used. Seed was sown by hand and during the vegetative period in 2016 / 2017 three basic factors were measured: sward height (three measurements on each plot using a sward stick), sod density and proportion of particular groups of plants (grasses, legumes, herbs and weeds) by the Weber method. Data were analysed by ANOVA.

Results and discussion

The difference in pasture height between two locations where the seed grasses were sown was observed. The results depended on soil moisture and grazing intensity. The undersown plots were characterised by higher sod density (+ 15%) compared to control plots without renovation. There was no effect of reseeding mixture on pasture production. Higher grazing intensities probably removed these effects.

Sod density was much higher on renovated plots than control plots. The renovated pastures showed a higher proportion of grasses in comparison to the control (Figure 1); the use of rotary cultivators reduced the competitiveness of the old sod. The undersown plots, after one year had a higher proportion of particular groups of plants, recommended for horses pastures (Davidson and Harris, 2007) than the control plots (Table 1).

The multi species mixture (A) dominated by *Lolium perenne*, *Festuca rubra* and *Poa pratensis* varieties is more suitable for pasture renovation than pure *Lolium perenne* mixture, especially in wet soil conditions. Aesthetic value of pasture when only *Lolium perenne* varieties were used was pretty good but unfortunately, the sod density was lower in comparison to mixture A.

Figure 1. Proportion of grasses, legumes, herbs and weeds in undersown and control plots.

Table 1. Sward height and sod density of undersown and control plots.

Mixture (the name)	Site moisure	Average measures factor[1]	
		Sward height [cm]	Sod density [%]
A (Relax)	P1 dry	5.57	76.67
	P2 wet	4.80	81.33
	average	5.18	79.00
B (Trawnik dosiewka)	P1 dry	5.33	73.00
	P2 wet	4.37	71.00
	average	4.85	72.00
C (Renowacja)	P1 dry	5.40	74.67
	P2 wet	5.13	75.67
	average	5.26	75.17
Control[2]	P1 dry	4.37	60.67
	P2 wet	5.07	59.00
	average	4.72	59.83
P1 dry	average	5.17	71.25
P2 wet	average	4.84	71.75

[1] Average for 12 measurements from the vegetation period 2016/2017.

[2] Old sward without undersowing.

Conclusion

Undersowing proved to be an effective method of renovation for horse pastures and contributed to the improvement of botanical composition of the test plots. Renovated pastures generally showed better parameters (height, decay, botanical composition) compared to the control plots without renovation. Multi species mixtures were characterised by a better sod density as opposed to a single species.

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Behavioural pattern of dairy cows in an automatic milking system with a 4-way grazing setup

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Abstract

Automatic milking (AM) has been successfully integrated into pasture-based commercial and research farms in Europe, Australia and New Zealand. A high voluntary cow flow is crucial for the success of AM in a pasture-based system. Previously, it has been shown, that providing three rather than two fresh grass allocations during the day improved the cow flow through the system. In order to achieve a good cow flow with increased cow numbers (> 80 cows per robot), a 4-way grazing system was set up in the present study. To examine the effect of the 4-way system on cow behaviour, 18 cows in a herd of 84 cows were monitored to establish their behavioural patterns. Behavioural monitoring was conducted using the RumiWatchSystem over a period of nine days. Graphical analysis of the daily behavioural pattern was conducted in three-hour summaries. Overall, the cows showed an average grazing time of 468 minutes day^{-1} and an average rumination time of 419 min day^{-1}. Those values align closely with values in the literature from conventional pasture-based milking systems, where cows spend 481 min day^{-1} grazing and 406 min day^{-1} ruminating. These results demonstrated that cows have sufficient time for natural behaviour in a 4-way grazing AM system.

Keywords: time-budget, chronobiology, circadian rhythm, grazing behaviour, milking robot

Introduction

The technology of automatic milking (AM) was first implemented in indoor-systems in the 1990s and has continued to increase in popularity. In addition to implementing AM in indoor housing systems, it has been proven that AM can be combined with pasture-based milk production (Davis *et al.,* 2006). Farms in New Zealand and Australia and parts of Europe have been successful in operating AM on pasture systems. A crucial parameter for the successful implementation of AM on pasture is a high voluntary cow flow to the robot and efficient cow flow around the farm. Diurnal feeding patterns and recommended grass allocations are important parameters influencing cow flow. Lyons *et al.* (2013) showed that a three-way grazing system improved cow flow through the AM system compared to a traditional two-way grazing system. To establish if a milking robot could operate satisfactorily with a higher cow number (> 80 cows per robot), a four-way grazing system was implemented. However, it was necessary to assess the suitability of this system with regard to the natural behavioural pattern of cows. Thus, the objective of this study was to monitor the grazing behaviour and activity of cows in the system using RumiWatch sensors.

Materials and methods

This study was conducted at the research farm of Teagasc Dairygold, Animal and Grassland Research Centre, Moorepark, Kilworth, Co. Cork, Ireland from 8 to 16 May 2017. This farm had a herd of 84 cows milked with an AM system (Lely Astronaut A4, Lely, Maassluis, the Netherlands). A four-way grazing system was in place with gate changing taking place at 04:00, 10:00, 16:00 and 22:00 hrs. Eighteen spring-calving dairy cows were randomly selected from the herd of 84 cows on the AM system. Primiparious cows were excluded due to lack of experience and training to the robot. The experimental cows were equipped with the RumiWatchSystem. The cows had an average of 42 ± 15 days in milk and an average milk yield of 27.7 ± 8.6 kg at the beginning of the experiment. All cows were Holstein-

Friesian and were maintained on a pasture diet (with < 0.5 kg concentrate/milking offered in the robot). The RumiWatchSystem, consisting of a noseband sensor and a pedometer, was previously validated for measuring grazing behaviour and activity by Werner *et al.* (2017a). The sensors were applied to 18 cows and behavioural and activity data were recorded continuously over a period of nine days. The data relating to the first day was excluded from subsequent analysis to allow for cow adaptation to the sensors. Subsequently, raw data were recorded in a 10 Hz resolution. These raw data were then converted by the RumiWatch Converter V.0.7.4.10 into three-hour and daily summaries. Microsoft Excel Version 2010 (Microsoft Corporation, Redmond, USA) was used for analysis of the data. The daily values of all cows were averaged and the standard deviation was calculated. For graphical analysis, the three-hour data were used to represent behavioural patterns during the day. Grazing time was calculated as the sum of EATUP (times when cows were chewing with head position up) and EATDOWNTIME (times when cows were biting/chewing with head position down). Grazing bite frequency was calculated as Number of Grazing bites/EATDOWNTIME.

Results and discussion

Behavioural characteristics of cows in a four-way grazing system are presented in Table 1. The data indicates that cows spent average times of 468 ± 166 min day^{-1} and 419 ± 93 min day^{-1} grazing and ruminating, respectively. Further, cows spent an average of 93 ± 42 min day^{-1} walking while taking 2,719 ± 1,240 strides day^{-1}. Kennedy *et al.* (2011) reported average rumination times of 406 min day^{-1} and Werner *et al.* (2017b) reported a walking time of 85 min day^{-1} in conventional milking systems. However, a study by O'Driscoll *et al.* (2010) reported that cows in a conventional milking system with a once-a-day or twice-a-day milking regime had longer lying times compared to the current study (620 ± 15 and 627 ± 14 min day^{-1}, respectively compared to 504 ± 218 min day^{-1}). This might be explained by the different stage of lactation or treatment.

The daily pattern of rumination and grazing time in a three-hour interval is displayed in Figure 1. There were two distinguishable periods of grazing 06:00 to 09:00 and 18:00 to 21:00, which were followed by intense rumination periods. These results show that the previously observed pattern of cows having two main feeding periods around dawn and dusk, a likely natural behaviour, is not impacted in a four-way grazing system. This study confirms that cows can express natural behaviour in a four-way grazing system. The study also provides initial results about cows' behaviour in a four-way grazing system. Further studies will report on cow location and behavioural data extended over a full lactation period.

Table 1. Mean values for different measured parameters with standard deviation (SD).

	MEAN	SD
Grazing time (min day^{-1})	468	116
Grazing bites (n day^{-1})	25,575	7,840
Grazing bites frequency (n min^{-1})	68	6
Grazing bouts (n day^{-1})	7	2
Rumination time (min day^{-1})	419	93
Ruminate chews (n day^{-1})	26,075	6,534
Rumination chews per bolus (n bolus^{-1})	53	7
Rumination bouts (n day^{-1})	14	3
Lying time (min day^{-1})	504	218
Standing time (min day^{-1})	843	196
Walking time (min day^{-1})	93	42
Strides (n day^{-1})	2,719	1,240

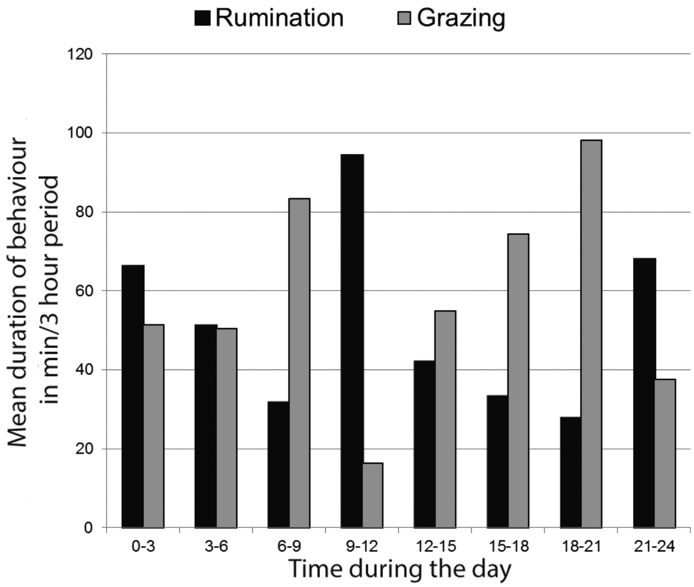

Figure 1. Mean values for grazing and rumination times per three hour-period over 24 hours.

Conclusion

To date, there are limited techniques to continuously monitor cow behaviour, consequently, little data has been generated up until now. Additionally, the four-way grazing system is a novel approach to allow more cows to be milked per robot in a pasture-based system. To the authors' knowledge, this is the first study to record such data. It may be concluded that cows on a four-way grazing system can maintain similar grazing and rumination times compared to cows in conventional pasture-based milking systems. The results also show that the studied cows followed a natural pattern of two large feeding bouts at dawn and dusk followed by two intensive rumination periods.

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Exploring the possibility to indirectly predict dry matter intake in lactating dairy cows

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Abstract

The potential to predict dry matter intake (DMI) of grazing dairy cows using grazing behaviour, activity monitors, linear type and body measurements, heart rate, blood pressure and infrared thermography was explored. The dependent variable DMI was estimated using the *n*-alkane technique on 120 spring calving Holstein-Friesian cows. To assess the association between the measurements of interest and DMI, using SAS PROC REG, multivariable regression models were constructed for each of the 46 individual measurements; adjustment variables (calving date, parity and feeding treatment) and known energy sinks (body weight and solids corrected milk yield) were forced into each model. To derive the final model, 13 variables associated ($P < 0.25$) with DMI were incorporated into a backwards linear regression procedure in combination with the same adjustment variables and known energy sinks. In addition to the adjustment variables and known energy sinks, the resultant model consisted of grazing bout duration ($P = 0.036$), eye temperature measured with infrared thermography ($P = 0.005$) and heart girth ($P = 0.016$). This model's R-square increased from 0.69 to 0.74 when compared to a model consisting of the adjustment variables and known energy sinks alone. Grazing bout duration and heart girth were positively associated with DMI, while eye temperature was negatively associated.

Keywords: dry matter intake, thermography, grazing behaviour, linear measurements

Introduction

Rising global food demand and high production costs have increased the importance of identifying animals with the capability to efficiently convert grazed grass to milk. Estimating DMI is a time consuming and expensive process and is impractical to conduct at commercial farm level on a pasture-based system. The objective of this study was to use novel animal measurements to explore the possibility of enhancing the predictability of DMI over and above that explained by known energy sinks and adjustment variables. This could pave the way for selective breeding for production efficiency as this would require DMI estimates for large numbers of animals.

Materials and methods

Dry matter intake was estimated for 120 Holstein-Friesian cows on three occasions, during 2015 (May, June and September), on the Teagasc Dairygold Research Farm, Kilworth, Co. Cork. All cows were part of a feed treatment study which ran concurrently (O'Sullivan *et al.*, 2015). Dry matter intake was estimated using the *n*-alkane technique as described by Mayes *et al.* (1986) and modified by Dillon and Stakelum (1989). Milk composition was recorded weekly and milk yields daily. Solids corrected milk (SCM) yield was calculated as described by Tyrell and Reid (1965). Muzzle circumference, hip width, back length, rump width and withers height were recorded once for each animal between the second and third DMI estimations. Heart girth, chest girth and body depth were measured twice, after the first grazing of a 36 hour allocation (full) and after the last grazing of a 36 hour allocation (empty) between the intake estimation periods. Body weight and body condition score were recorded the week before and after DMI. In May, each cow was linear scored by the Irish Holstein Friesian Association. Each animal was fitted with a polar heart rate monitor to record heart rate every second over a 24 hour period. Three blood pressure measurements were taken within one milking between August and September. Animals were fitted with Institute of Grassland and Environmental Research behaviour recorders for a 24 hour period between each intake run. Graze analysis software was used to analyse recorded jaw movements and to calculate total grazing, ruminating and idling times, the number of mastications, prehensions, grazing and ruminating bouts. Images of the eye, ribs, front and back hooves were captured using an IRT camera after the second intake run as outlined in Byrne *et al.* (2017).

In total, 46 multivariable regression models were fitted using SAS PROC REG to assess the association between each of the measurements of interest and DMI; adjustment variables (calving date, parity and feeding treatment) and known energy sinks (body weight and solids corrected milk yield) were forced into each model. Variables that had a *P*-value of less than or equal to 0.25 were retained for backward linear regression to construct the final model where variables with a *P*-value < 0.05 were retained in the model. Model residuals were standardised and normality checks were performed.

Results and discussion

The combination of known energy sinks and adjustment variables accounted for 69.6% of DMI. The adjustment variables had the expected results; parity ($P < 0.001$), SCM ($P < 0.001$) and body weight ($P = 0.006$) were positively associated with DMI. Date of calving ($P = 0.789$) did not have a significant effect on DMI. Feeding treatment was accounted for and had a significant effect (Table 1).

After the multivariate regression phase, 13 variables progressed to the backward regression phase. Of these variables, full heart girth ($P = 0.016$), grazing bout duration ($P = 0.036$) and average eye temperature ($P = 0.005$) were retained in the model. This model's R-square increased from 0.69 to 0.74 when compared to a model consisting of the adjustment variables and known energy sinks alone.

Due to noteworthy changes in the *P*-value of body weight between the model with the known energy sinks ($P = 0.006$) and the *P*-value of body weight in the results from the backward model ($P = 0.938$),

Table 1. *P*-values associated with known energy sinks, adjustment variables and variables of interest in model with known energy sinks and adjustment variables only and the final model

Variable	Known energy sinks and adjustment variable *P*-values	Variables retained in the backwards model *P*-values
Parity	<0.001	0.001
Parity 1[1]	<0.001	<0.001
Parity 2[2]	0.083	0.131
Feeding treatment	<0.001	<0.001
Feeding treatment 1[3]	<0.001	<0.001
Feeding treatment 2[4]	<0.001	<0.001
SCM	<0.001	<0.001
Body weight	0.006	0.938
Calving date	0.79	0.933
Grazing bout duration		0.036
Full heart girth		0.016
Average eye temperature		0.005

[1] Second lactation compared with first lactation and all lactations greater than second.

[2] Third or greater lactation compared with first and second.

[3] Low grass allowance compared with control and high concentrate.

[4] High concentrate compared with control and low grass allowance.

further investigation was undertaken. A review of the results from the univariate modelling step revealed a degree of collinearity between body weight and full heart girth. The relationship between body weight and DMI, body weight and heart girth, and heart girth and DMI was investigated using SAS PROC CORR. The correlation of body weight and DMI, body weight and heart girth, and heart girth and DMI were 0.416, 0.420 and 0.838 respectively, all had a *P* value of < 0.001. When body weight is removed from the final model the R-squared is unaffected.

Conclusion

The inclusion of grazing bout duration, full heart girth and average eye temperature, in addition to SCM, body weight, calving date and parity while accounting for stocking rate treatment effects increased the predictability of DMI to 74.3%. The increase in ability to predict by 4.7% means this may become a viable method of estimating DMI on commercial farms as the use of automation increases.

The relationship between full heart girth and body weight suggests that measuring heart girth may be a cheap alternative to installing and calibrating weighing scales for weighing cows at farm level. All of these findings will be validated using an independent dataset.

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Theme 3.
Environmental influences on grassland systems – consequences of climate change, mitigation strategies, and impacts on ecosystems

The carbon sequestration of grassland soils – climate change and mitigation strategies

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Abstract

Grasslands play a key role in the provision and regulation of important ecosystem services across many livestock production systems in Europe. From a climate change perspective grassland soils have the ability to sequester atmospheric CO_2, thus potentially contributing to climate change mitigation. The sequestration of carbon (C) in grassland soils is regulated by complex biogeochemical processes, which are in turn affected by both management and by multiple environmental factors. There are still large uncertainties relative to the accurate estimation of C sequestration rates in grassland soils due, for example, to the high spatial and temporal variability of soil C stocks. According to the scientific literature, annual C sequestration rates can vary between -2.2 (loss) and 2.5 (gain) mg C ha^{-1} yr^{-1}, with a mean of 0.79 ± 0.16 mg C ha^{-1} yr^{-1}. Here we summarise recent research findings from both short and long term grassland studies to show how soil C accumulation may change under different management practices and environmental conditions. We specifically discuss how (1) climate, (2) soil physical properties, (3) grassland type and age (i.e. temporary or permanent), (4) nutrient fertilisation, (5) grazing, and (6) intensity of grassland use may ultimately influence the C balance of agricultural grasslands.

Keywords: grassland intensification, soil organic carbon, management

Introduction

Managed grasslands across Europe represent important ecosystems which provide key services to human society including food production, the regulation of nutrients and water and the sequestration of carbon (C) in soils. Grassland soils across different livestock-based systems can act either as sinks or sources for atmospheric CO_2 and may thus significantly contribute to the C footprint associated with common agricultural practices.

There is growing interest in agricultural grassland soils and their Green House Gas (GHG) mitigation potential partly because the livestock sector is responsible for approximately 14.5% of all anthropogenic GHG emissions worldwide (Gerber *et al.*, 2013) and also because land owners, farmers and major food production companies are now aiming to promote healthier and more fertile soils, which sequester C and reduce the C footprint of key commodities such as milk and meat. Evidence from multiple European grassland sites show that soil C sequestration rates may reach (1) 0.05 mg C ha^{-1} yr^{-1} according to inventories of soil organic C stocks or (2) 0.77 mg C ha^{-1} yr^{-1} for mineral soils according to C flux balance measurements (Soussana *et al.*, 2010).

Important research gaps remain about what overall long-term effects grassland management (and in particular grassland intensification) might have on the 'Net' Carbon balance of many grassland systems in Europe. Common management practices involve the addition of nutrient and non-nutrient fertilising materials (i.e. liming) to soils, animal grazing, grassland reseeding and changes in land use, which all interact to affect soils' ability to sequester C.

For example, recent findings from long-term studies and meta-analyses show how both inorganic (Fornara *et al*., 2013) and organic nutrient fertilisation (Maillard and Angers, 2014; Fornara *et al*., 2016) significantly influence soil C sequestration. N-induced effects on soil C storage include changes in (1) organic matter decomposition, (2) below ground C allocation to root mass and mycorrhizal exudation, (3) C allocation to different soil organo-mineral fractions, (4) microbial composition and activity such as the suppression of heterotrophic respiration or changes in extracellular enzyme activities.

Similarly, the application of agricultural lime can have neutral or positive effects on soil C stocks in permanent grassland (Fornara *et al.,* 2011; Egan *et al*., 2018). Beyond the potential effects that the addition of nutrient and non-nutrient fertilising materials have on soil C storage, the frequency and intensity of biomass removal from agricultural grasslands (i.e. herbage use) also plays a key role in influencing the C balance of grasslands. Under intensive grazing it could be that up to 60% of the above-ground DM production is ingested by domestic herbivores (Lemaire and Chapman, 1996). A large part of this grass intake is digestible, however, non-digestible C and N intake, which could vary between 25 and 40% of total biomass ingested, is returned back to the pasture in excreta (mainly as faeces). Even when more than 80% of above-ground primary production is harvested within intensive cutting regimes, and exported away as hay or silage, this C loss may be compensated by organic C imports through farm manure and slurry applications. The intensity of herbage use not only affects the amount of C (and N) returned to the soil but also affects plant photosynthetic capacity and carbon allocation, with implications for plant-plant interactions (i.e. plant growth strategies) and community-level productivity (Diaz *et al*., 2007) (see Figure 1). Moreover, the intensity of defoliation mediates plant-soil interactions by influencing the quality and quantity of root exudates and litter inputs to the soil (Wardle *et al*., 2004) and by altering the mean residence time of soil organic matter carbon pools (Klumpp *et al*., 2007, 2009). For that reason, intensive biomass use reduces C sequestration.

To maintain long-term biomass production and forage quality, grasslands are often embedded in crop rotations or go through phases of grassland renewal (i.e. reseeding). In particular, the process of ploughing is intrinsically coupled with high levels of soil disturbance, which reduces soil C, either through soil layer mixing or through the breakdown of soil aggregates (Conant *et al*., 2001). Soil disturbance also significantly influences nutrient cycling (Al-Kaisi *et al*., 2005) and soil N mineralisation processes (Smith, 2014).

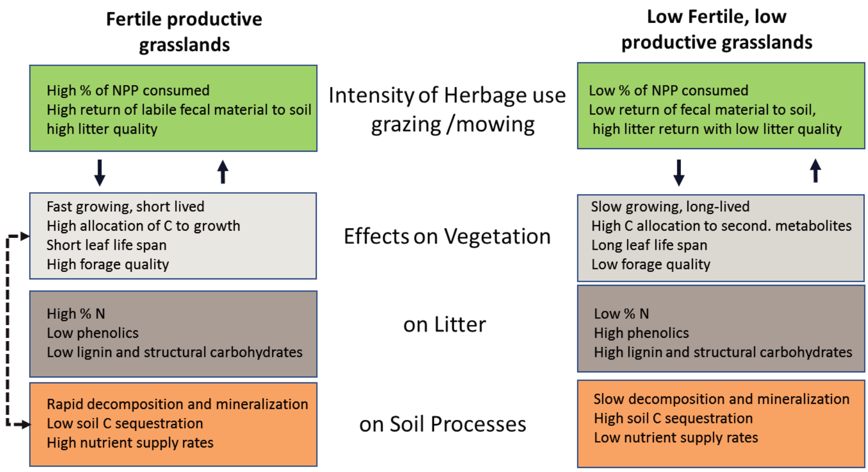

Figure 1. Effects of herbage use intensity on fertile systems that support high herbivory and low fertile habitats that support low herbivory. Morphological vegetation traits are determinants of the quality and quantity of resources that enter the soil and subsequent soil processes. The linkage between belowground and aboveground systems (dotted line), (adapted from Wardle *et al*., 2004).

The response of soil organic C (SOC) to changes in land use or grassland management is often non-linear, and there is evidence that C is lost more rapidly than it is gained after a change in land use (Soussana *et al.*, 2004). Nonetheless, the periodic tillage and re-sowing of short-duration grasslands may have the potential for soil C accrual in-between crops and permanent grasslands. Mean soil C sequestration tends to increase with the lifespan (i.e. age) of grasslands (Maillard 2012; Wang *et al.*, 2014), however, it is not clear how long it will take (and if) it will eventually reach an equilibrium state (e.g. Smith, 2014). The simultaneous interaction of numerous management practices (e.g. nutrient fertilisation, liming, grazing, etc.) and the effect of climate change on soil ecosystems may 'prevent' soil C stocks from reaching an equilibrium, which is expected to occur in undisturbed systems under constant conditions.

The potential for sequestrating C should also be addressed in deeper soil layers including the contribution that changes in plant rooting depths of forage species in soil fauna and hydrology may have on soil C dynamics and storage. Below 30 cm depth, C residence time in soils is longer; however, owing to the low influx of C within these horizons, this C accrual process remains slow (Torres-Sallan *et al.*, 2017).

Here we quantify the effects that different management practices may have on soil C sequestration by using key findings from previous studies. We provide evidence for a carbon sink in managed grasslands and we address drivers of soil accumulation and describe trade-offs which could either increase or decrease soil C storage.

Materials and methods

In order to get a comprehensive view of multiple grassland ecosystems, which vary in terms of management, age, soil properties, climate, etc., we have gathered data from 50 literature studies, available open experimental field site networks (e.g. 40 grassland sites from European flux database, projects) and five chronosequences. Two methods can be used to estimate the C balance of a grassland field: (1) direct measurements of soil organic C stock change, and (2) carbon flux measurements which allow C balance calculation.

Soil organic carbon stocks

This method is based on soil sampling and on repeated measurements over time. Here a sampling site is revisited (re-sampled) every one to five years. Results are commonly analysed as C content at time x (tx) vs baseline (t0), using regression analysis to detect trends in SOC stocks over time when several measurements are available. The second approach is the point-in-time measurement against an assumed business-as-usual baseline. This approach compares SOC stocks at different sites at one single time after a contrasting management was implemented and does not require a baseline measurement. However, this method underlies the assumption that the compared sites were exactly the same prior to the change in management (in terms of soil type, climate, land use). Disadvantages of this method are that most studies concern only the top-soil (e.g. 0 to 30 cm), although C sequestration or loss may also occur in deeper soil layers. This is related to the fact that management effects are greatest at the surface and decline with depth in the profile (Ogle *et al.*, 2004). About 44% of the total C pool (down to 1 m soil depth) is located within the top 30 cm (Stahl *et al.*, 2016; Soussana and Lemaire, 2014). The uncertainties concerning the estimated values of C storage or release after a change in grassland management are still very high.

Carbon fluxes in grassland ecosystems

An alternative to the direct measurement of changes of soil C stock in grasslands is to measure the net balance of C fluxes (i.e. net C storage, NCS) exchanged at the system boundaries. This approach provides a high temporal resolution and changes in C stock can be detected within one year, in contrast to direct measurements of stock change which require several years or several decades to detect significant effects. The main drawback of flux measurements, however, is that several lateral C fluxes need to be measured to get a full C balance; as the NCS (g C m^{-2} $year^{-1}$) is the mass balance of these fluxes. In temperate systems, net C storage (see Soussana *et al.*, 2007, 2010) can be estimated as:

$$NCS = (F_{CO2\text{-}C} - F_{CH4\text{-}C}) + (F_{manure} - F_{harvest} - F_{animal\text{-}products}) - F_{leach}$$

where $F_{CO2\text{-}C}$ is the net ecosystem exchange of CO_2 between the ecosystem and the atmosphere, $F_{CH4\text{-}C}$, F_{manure}, $F_{harvest}$ and $F_{animal\text{-}products}$ are lateral organic C fluxes (g C m^{-2} per year) which are either imported or exported from the system. F_{leach} are organic (and/or inorganic C losses in g C m^{-2} per year) through leaching. In the present paper, we present findings from both methods.

Although a large number of literature studies were included in our analyses, these research papers presented not always complete information, necessary to estimate soil C stock changes. Furthermore, information was sometimes missing on key aspects of specific management practices including grazing (type and pressure), mowing (yield and number of cuts), grassland age and nutrient fertilisation regimes. We only retained papers with the necessary information. For studies and measurements which were longer than one year, we used annual means. We, thus, summarised findings from ~50 studies including 400 study sites, spanning across numerous continents (EU, US, AU, NZ) and covering a wide range of conditions in terms of climate (MAT -1.5 to 23 °C, MAP: 130 to 1,700 mm), soil properties (SOM 35 to 90%), grassland age (zero to 80 yrs), management (grazing 0.1 to 4.8 LSU ha^{-1} yr^{-1}; mowing 1 to 10 t DM ha^{-1} yr^{-1}), and nutrient fertilisation (zero to 400 kg N ha^{-1} yr^{-1}). We also accounted for the differences in grazing management (continuous vs rotational) and permanent vs temporary sown grasslands.

Results and discussion

According to our data synthesis, managed grassland ecosystems act as potential sinks of C storing on average 0.7 ± 0.16 mg C ha^{-1} yr^{-1}. Our evidence is that C accumulation rates range from -2.2 (loss) to >1 mg C ha^{-1} yr^{-1}. However, there is large variability in soil C accrual when compared across different continents (EU 1.1 ± 0.2, US: 0.2 ± 0.2, NZ/AU: 0.1 ± 0.2 and other 0.2 ± 0.01), which can be partly explained by differences in climate, grassland community vegetation (i.e. species composition, presence/absence of C3 or C4 grasses, etc.) and herbage use in terms of quantity and type (animal density and type, mowing). Another point which has to be mentioned here and which was addressed by previous meta-analyses (e.g. Derner and Schumann 2007; Conant *et al.*, 2001, 2017; Zhou *et al.*, 2016; Lu *et al.*, 2017), is that there is considerable bias due to the lack of available data and to publications which include incomplete information.

It is important to remember that the potential for C sequestration of a given soil in time and space will depend on both present and past management ('legacy effect') and thus to the time since management was implemented. This is the starting point from which changes in soil organic C will occur. SOC stocks changes quite rapidly (i.e. increases) after an improved management regime is implemented, but over time the rate of SOC increase progressively declines (Johnston *et al.*, 2009; Minasny *et al.*, 2017). Generally, soils with low soil organic matter content (SOM) can sequester more C and for longer periods of time before a maximal C sequestration 'rate' (expressed as C sequestered per SOC stock, see also 4permille-initiative) is eventually reached when compared to soils with high SOM (Figure 2).

As soils approach a new equilibrium (where carbon 'flow in' equals carbon 'flow out'), perhaps after 30 to 70 years since initial disturbance (i.e. arable to grassland and grassland reseeding), the net removal of CO_2 from the atmosphere becomes very low (Figure 1). However, this equilibrium can to a certain extent be influenced by current management practices (e.g. changes in fertilisation, liming, grazing or mowing regimes may either delay or accelerate the occurrence of an equilibrium state). It could be that recently established (< 3 to 5 yr old) sown grasslands and 'improved' old permanent grasslands have similar soil

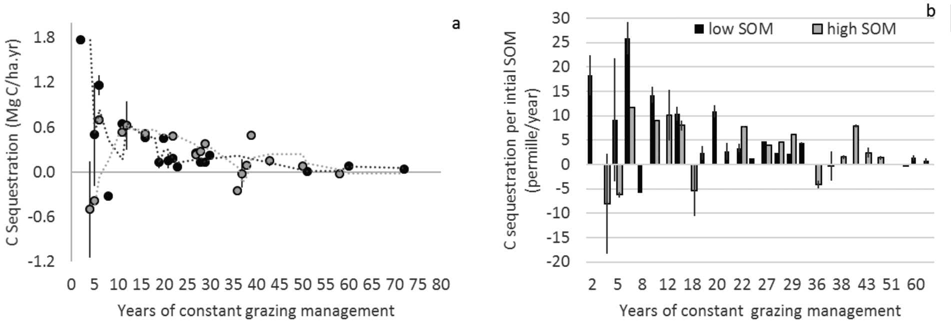

Figure 2. Soil C sequestration rates (a) and soil C sequestration per initial SOM content (expressed in ‰, b) as a function of the number of years since management practices were implemented on different soil types with high and low SOM content (*low*: dark grey; *high*: light grey). Management changes involved both arable to grassland and grassland reseeding. Data are mean values from four studies (see Maia *et al.*, 2009; Wang *et al.*, 2014; Kohler, 2014; Carolan and Fornara, 2016).

C sequestration rates (e.g. Figure 3) but these rates of C accumulation can greatly change under different management practices. Despite high variability associated with the effects of different practices, a primary management goal should be to maintain existing soil C stocks because grassland intensification will likely contribute to decreases in the SOM pool. The choice of 'best' grassland management (grazing vs mowing vs both practices) plays an important role in maintaining the grassland sward and could avoid frequent grassland renovation and ploughing of the grassland sward.

Management effects on herbage quality and quantity: implications for C balance

Grazing has a large direct impact on grassland productivity, plant community structure and biogeochemical cycling (see Figure 1). Grazing animals promote spatial heterogeneity in C, N and P pools and fluxes via uneven patterns of defoliation and animal returns. Consequently, grazed grasslands are a mosaic of patches of variable vegetation height and feed quality, depending on the presence or absence of urine and dung wastes. Under mowing, all aboveground biomass is removed homogeneously, and no excretion (i.e. nutrients) returns to the field, thus changing litter production and plant nutrient status in the absence of fertilisation. If defoliation by grazing and mowing is too intense and/or the period between successive defoliation events is too short, the amount of green plant biomass can be reduced and growth/carbon capture is reduced. Herbage and litter production respond to defoliation pressure within this range;

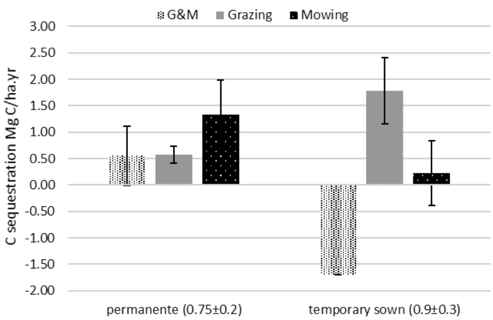

Figure 3. Mean annual C sequestration rate (Mg C ha^{-1} yr^{-1}) of permanent (n = 76) and temporary sown (n = 11) grasslands as a function of management practices, grazing, mowing and mixed (G & M). Data are means ± SE. Note analysed literature and data did not provide information on grassland age.

higher herbage removal increases herbage quality (given there is sufficient N available) and reduces litter production, and *vice versa*. There is, therefore, a tradeoff between herbage quality (promoting animal production) and litter production (promoting carbon sequestration).

Cutting vs grazing and fertilisation

A comparison between grazing and mowing regimes reveals that grassland soils are likely to sequester more C under moderate N additions. However, in mixed grazing and cutting systems there is evidence of lower soil C-sequestration than under pure grazing systems (Figure 3). This may be possibly explained by more animal wastes (faecal deposition) and plant litter inputs under grazing-only when compared to mixed grazing and cutting systems where C inputs to soils are drastically reduced. Thus, grazing exerts positive effects on soil C sequestration when it is practiced alone and not in combination with cutting regimes.

Concerning different grazing and stocking systems (continuous vs rotational), there is little information available in the literature on the (appropriate) grazing management such as improved grazing management, including adjustment in animal stocking rates, periodical removal of grazing livestock and length of the grazing period (e.g. rotational or short duration grazing, seasonal grazing, etc.). Even so, data suggests that under comparable herbage use, the soil C sink is higher under continuous than under rotational grazing, in particular, when fertilised.

C sequestration – Herbage use

To compare management regimes, intensity of management practices were converted to the quantity of herbage mass removed by grazing, mowing and mixed grazed-mown systems (Figure 5). Analyses show that soil C sequestration increases at increasing biomass removal by grazing animals and by mowing. As for mixed systems, excessively intense herbage use tends to decrease soil C sequestration which is possibly also accompanied by C losses from soils. For grazed systems, C sequestration increases until a threshold (critical amount of herbage mass is removed) is reached, which depends on the fertilisation regime (i.e. two maximums).

Under moderate fertilisation, grazed and mown systems seem to underlie the same critical herbage mass removal (i.e. threshold), whereas frequent mowing seems to reduce C sequestration more rapidly when defoliation is too intense (Figure 5). Grazing animals promote nutrient recycling and returns to the field.

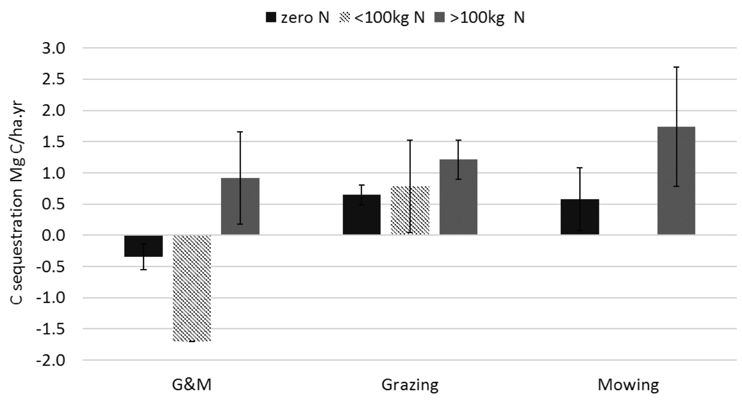

Figure 4. Mean annual C sequestration as a function of management practices (grazing, mowing and mixed; G & M) and fertiliser addition (zero: dark grey; < 100 kg N ha^{-1} yr^{-1}: dotted; >100 kg N ha^{-1} yr^{-1}: light grey). Data are means ± SE (with n = 6 for G & M, n = 42 for grazing and n = 17 for mowing).

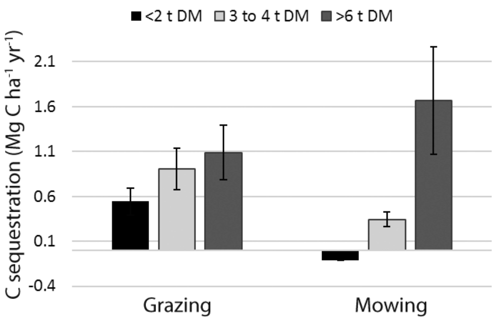

Figure 5. Mean annual C sequestration as a function of removed herbage mass (tonnes DM ha^{-1} yr^{-1}) and management practices for grazing (n = 66) and mowing (n = 16) with light (< 2 t DM ha^{-1} yr^{-1}; black) moderate (3 to 4 t DM ha^{-1} yr^{-1}; light grey) and intensive (> 6t DM ha^{-1} yr^{-1}; dar grey) herbage use.

Moreover, in grazed systems not all available biomass (i.e. net primary production, NPP) is consumed (ingested) by animals, creating, except for very intensive systems, a mosaic of patches (i.e. spatial heterogeneity) of variable vegetation height (including biomass and litter production), with or without the presence of urine and faeces. This variability of vegetation and related soil properties across space has thus the potential for significant effects on biotic interactions and plant-soil feedbacks ecosystem where C sequestration is promoted.

Nonetheless, grazed, mown and fertilised systems do underlie a number of trade-offs which need to be considered when improving soil C sequestration and especially whole GHG balance. There are unavoidable trade-offs between: (1) leaf removal (i.e. removal of photosynthetic plant biomass) and litter and root production (i.e. C inputs to the soil) throughout the year, (2) forage quality (i.e. digestibility) and litter decomposability of vegetation and, thus, mean residence time of soil organic C, and (3)

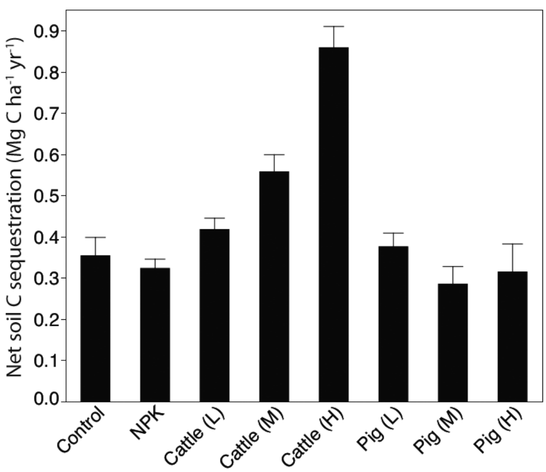

Figure 6. Rates of soil C sequestration (0 - 15 cm soil depth) under either organic or inorganic nutrient additions or no-nutrients (i.e. control). Nutrient application rates: NPK = 200 kg N, 32 kg P, 160 kg K ha^{-1} yr^{-1}; Pig (L), Pig (M) and Pig (H) = Pig slurry applications at 50 (Low), 100 (Medium) and 200 (High) m^3 ha^{-1} yr^{-1}, respectively; Cattle (L), Cattle (M), Cattle (H) = Cattle slurry applications at 50 (Low), 100 (Medium) and 200 (High) m^3 ha^{-1} yr^{-1}, respectively (Fornara *et al*., 2016).

maximisation of herbage use by grazing and mowing and emissions of enteric CH_4 and N_2O from urine and fertilisation.

Effects of organic vs inorganic nutrient fertilisation on soil C accumulation

Most agricultural grasslands receive significant nutrient inputs either in organic or inorganic forms, which could influence soil C cycling and storage in different ways.

For example, findings from a long-term study under Irish conditions show how cattle slurries are associated with greater rates of soil C sequestration when compared with NPK additions (Figure 6) and pig slurries. This is possibly because of indirect pig slurry effects on soil microbial communities and soil biogeochemistry (e.g. priming effects) or to lower average C inputs from pig slurries (0.27 to 1.1. mg C ha^{-1} yr^{-1}) when compared to cattle slurries (0.92 to 3.67 mg C ha^{-1} yr^{-1}).

Effects of the intensity of grassland use by grazing, mowing and fertilisation can be summarised as descibed in Figure 7.

C sequestration – under changing climate

Increases in SOC may partly reduce atmospheric CO_2 levels, thus, mitigating human-induced climate change. However, biotic and abiotic feedbacks between soils and climate variability could make soils' ability to sequester C more vulnerable and unpredictable. For instance, inter-annual variability in temperature and rainfall significantly affect net primary production, litter inputs and decomposition (e.g. soil respiration) leading to an inter-annual variability in soil C dynamics and storage.

For instance, depending on growth stage of biomass and respective management practices (mowing vs grazing and intensity), short term and/or extreme temperature events (and a reduction in precipitation) have different impacts on ecosystems. Under high aboveground biomass (i.e. highly active biomass production), drought results in a severe decline of photosynthetic activity leading to biomass dying,

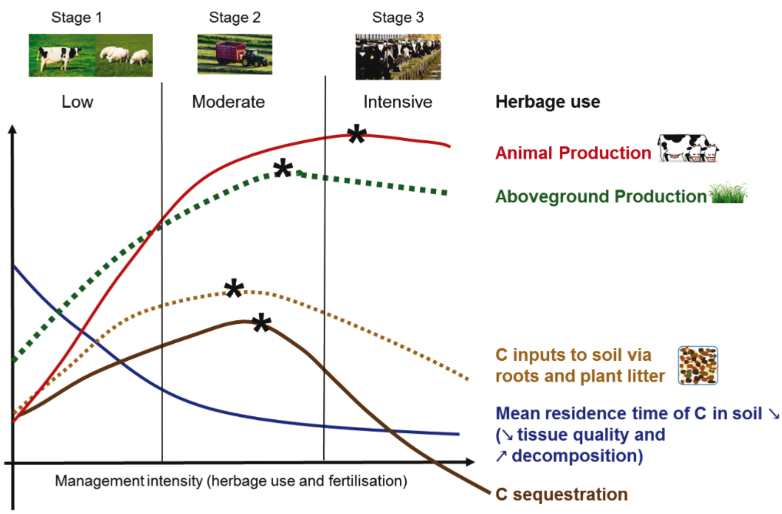

Figure 7. Effects of management intensity by grazing, mowing and fertilisation on C inputs, mean residence time of soil organic C and C sequestration. Management practices can be attributed to the three intensity stages: (1) low herbage use often found in grazed systems; (2) moderate herbage use often found in mown and grazed systems, and (3) intensive systems aiming to maximise animal production. Stars are maximal/optimum values for each variable (adapted/modified from Soussana and Lemaire 2014).

long recovery times and, thus, a reduction in C sequestration potential (Zwicke *et al.*, 2013). Instead, under moderate aboveground biomass (as a result of early season mowing/grazing), vegetation recovery is faster, maintaining primary production and C sequestration potential (Klumpp *et al.*, 2011). Notably, under low aboveground biomass (i.e. intensive herbage use) drought periods can lead to severe vegetation and soil degradation with long recovery times and soil erosion.

Likewise, potential climate change effects on soil C accumulation will be mediated not only by changes in grass yields but also by changes in soil-plant-microbial interactions which ultimately influence the amount of C that is lost or gained in soils. For example, increases in soil microbial activities may enhance soil respiration and C losses but could also be associated with higher litter decomposition and more organic C being processes, incorporated and stabilised into smaller, more recalcitrant soil organo-mineral fractions (Cortrufo *et al.,* 2013).

Regarding long-term climate changes within Europe, increasingly warmer and wetter winters are expected in the north and increasingly warmer and drier summers in the south (see Ergon *et al.,* 2018). Accordingly, biomass production are likely to face more drought in the future in many Mediterranean areas, while warming (and possible increases in CO_2 concentration) in Nordic regions will increase forage production (Figure 8).

In both regions, climate change will affect forage quality and lead to modifications of the annual productivity cycles, with an extended growing season in the Nordic region and a shift towards a peak of the grass growth curve in autumn/winter in the Mediterranean region. This will require adaptations in defoliation and fertilisation strategies, as well as species and mixtures with optimal performance.

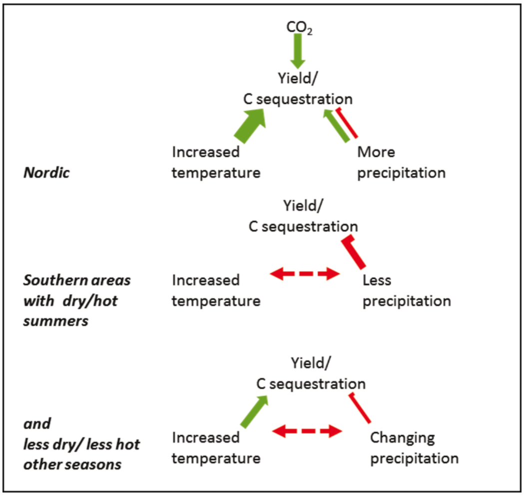

Figure 8. Effects of climate change on forage production and C sequestration (positive effects indicated by green arrow and negative effects indicated by blunted red arrows, interactions are indicated by broken lines). In the Nordic region, increased temperature and elevated (CO_2) will increase grassland productivity during the growing season. In more southern areas, less summer precipitation will override all other effects, while the rest of the year and in less dry areas, the positive effects of increased temperature will override the negatives of less precipitation (C), (adapted from Ergon *et al.*, 2018).

Conclusion

Managed grassland soils can act as CO_2 sinks because there is evidence of positive rates of soil C accumulation across different climates and management practices.

- Soil C sequestration rates tend to decrease over time assuming that no management changes have occurred.
- Usually low SOM soils have greater rates of C accumulation compared to high SOM soils after a disturbance event (land use change). It is not clear when equilibrium will eventually be reached because of the interactions of different factors including the intensity of management practices.
- As for management practices, they are region-specific (i.e. pedo-climatic conditions). Improved management of herbage use and fertilisation may increase soil C sequestration, the effect, however, varies depending on the timing, frequency and intensity in use. There is a threshold or critical herbage use where C sequestration declines or even becomes negative when C exports are too intense.
- Concerning type of herbage use, grazing seems to have an advantage on grasslands being formed due to climatic conditions (e.g. uplands and extensively used areas), as mowing may have positive effects in certain cases.
- Organic amendments (animal slurries) have usually positive effects on soil C accumulation when compared to artificial fertiliser applications. However, animal slurries are different (cattle vs pig) and could lead to different soil responses in terms of C accrual.

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Optimising ecosystem services provided by grassland systems

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Abstract

Grasslands are multifunctional, producing forage for livestock while providing a wide array of ecosystem services. The value of grasslands for society thus extends far beyond their direct economic value for livestock production. Nevertheless, some antagonisms exist between benefits that can potentially be provided by grasslands. Hence, optimising the delivery of multiple benefits requires consensual decisions. This paper gives an overview of the current state of knowledge about ecosystem services provided by grasslands and discusses trade-offs at the field and the farm scales and how to evaluate them. Management options are available at the field scale to improve provisioning, regulating or maintenance services (biodiversity conservation, climate change mitigation or the regulation of nutrient cycles). Multi-species swards with an optimal legume abundance stand out as facilitators of multiple ecosystem services. However, the different services are maximised at different levels of grassland intensification and none of the options available at the field scale alleviates the conflicts occurring along the intensification gradient. We conclude that multiple services can be optimised by combining specific improvement measures at the field scale with heterogeneity in management intensity, involving multiple grassland types, at the farm or landscape scale.

Keywords: production, biodiversity, carbon storage, nutrient cycling, multi-criteria analysis

Introduction

Society expects much more from grassland-based agricultural systems than milk and meat products (Dumont *et al.*, 2016). Grasslands supply multiple ecosystem services (ESS – provisioning, regulating, maintenance and cultural) to a greater or lesser extent depending on their management, botanical composition, location within the landscape and pedo-climatic conditions (Duru *et al.*, 2015). In the scientific literature, the term 'ecosystem services' (ESS) is used to refer to various concepts (Plantureux *et al.*, 2016). Here, we follow the definition of the 'Common International Classification of Ecosystem Services – CICES' (Haines-Young and Potschin, 2013). This definition distinguishes ESS from ecosystem goods and benefits, which is crucial to properly evaluate ESS of agro-ecosystems. Indeed, the delivery of agricultural goods is supported by both ESS and agricultural inputs (Palomo *et al.*, 2016). According to the CICES, ESS 'retain a connection with the underlying ecosystem functions, processes and structures that generate them', while goods do not. The supply of goods is a primary goal of agriculture and so we also discuss it in this paper.

The relationships among ESS can be synergetic or antagonistic, non-linear and scale sensitive (Bennett *et al.*, 2009). The simultaneous evaluation of multiple ESS is essential to assess multifunctionality but it is also challenging. Moreover, the valuation of ESS is influenced by the socio-economic context and is thus highly sensitive to local conditions (Dumont *et al.*, 2016). We distinguish between 'antagonism' among ESS, when the provision of one ESS declines concomitantly with the increase of another one, and 'trade-off', when beneficiaries choose a balance between various benefits provided by the system. It follows that trade-offs imply a weighting of the benefits, while antagonisms simply describe a type of relationship among ESS. This nuance is a complement to the typology of ESS relationships proposed by Bennett *et al.* (2009). In addition, we define 'field' as a uniformly managed land area. In this review article we highlight options to enhance the supply of ESS from grasslands. We focus on the effect of agricultural management, often through its impact on the grassland plant community, on the delivery of provisioning, regulating and maintenance services. Methods to evaluate multiple ESS and the supply of ESS at the landscape scale are also discussed.

Management options optimising the supply of ESS

Provisioning ESS

Forage for ruminants has been the primary motivation for grassland creation and remains the chief good delivered by grasslands. Huyghe *et al.* (2014) reported maximum yields of up to 20 t DM ha^{-1} and identified temperature and water availability as the main drivers for the huge yield variability in Europe. Often, a large spatial variability in grassland yield also exists at the local scale, depending on soil characteristics, microclimate, topography, botanical composition and management (inputs of nutrients, water, labour and energy). In the Mediterranean region, for example, rainfed semi-natural grasslands produce on average as little as 2 t DM ha^{-1} whereas irrigated and fertilised ones yield up to 15 t DM ha^{-1} (Smit *et al.*, 2008). The yield increase in this case is mainly due to an increase in agricultural inputs, although alleviating drought conditions may also improve ecosystem functioning (for instance nutrient availability). Thus, only a fraction of the yield gains arise from an increase in ESS. The importance of distinguishing provisioning ESS from total yield is well exemplified by the effect of grass-legume mixtures on crude protein yield (Figure 1). If the nitrogen (N) yield of a pure grass sward is enhanced by increased N fertilisation, the increase in provisioning ESS is marginal because nearly the entire additional yield originates from fertiliser (1). If N yield is enhanced by the inclusion of legumes in the sward, the increase in provisioning ESS is tremendous, mainly by symbiotic N_2 fixation (SNF; 2). On the contrary, if grass-legume mixtures receive additional N fertiliser, the provisioning ESS decreases even if the yield is maintained because SNF declines (3).

The botanical composition of the grassland, and especially the presence and proportion of legumes, greatly affects the delivery of provisioning ESS (Figure 1). Legumes, in mixtures with grasses generally boost biomass and crude protein yields (Finn *et al.*, 2013; Suter *et al.*, 2015), as well as weed suppression (Connolly *et al.*, 2017). Forbs may also promote high provisioning ESS by multi-species grasslands as indicated by Husse *et al.* (2017) for *Cichorium intybus* L. and of Cong *et al.* (2017) for *Plantago lanceolata* L. Forbs widens the range of functional trait values in the community (for instance range of rooting depths). However, the positive effect of forbs on provisioning ESS seems weaker and less consistent than that of legumes combined with grasses. Mixture effects on provisioning ESS may differ under grazing as compared to mowing partly because of selective grazing by livestock. Nevertheless, increasing botanical complexity from one to five species (two grasses, two clovers and chicory) has been shown to increase daily milk production of dairy cows under intensive rotational grazing (Roca-Fernández *et al.*, 2016).

The second key aspect of forage provision is its quality for the livestock as determined by its digestibility, palatability and its content in energy, protein and other compounds (Huyghe *et al.*, 2008). Forage digestibility and protein content decrease with increasing plant maturity and the associated formation of structural tissues, but very frequent defoliations aimed at harvesting young forage usually reduce annual biomass yield (Pontes *et al.*, 2007), increase harvesting costs and is detrimental to several ESS (following sections). Annual yield needs to be traded off against forage quality. At the field scale, forage yield can be increased without compromising forage digestibility and protein content by adjusting the relative legume abundance in the sward (Sturludóttir *et al.*, 2014). Otherwise, trade-offs between forage quality

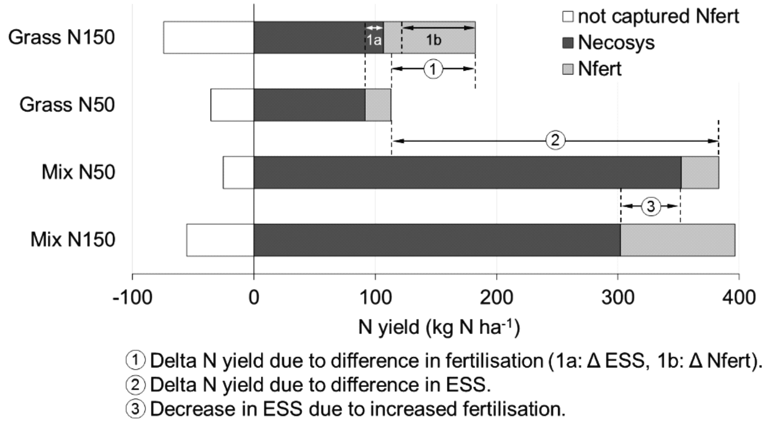

Figure 1. Nitrogen (N) yield of pure grass swards (Grass) and grass-legume mixtures (Mix) fertilized with 50 or 150 kg N ha^{-1} yr^{-1}. Nfert: N from fertiliser applications, Necosys: N from the ecosystem (symbiotic N_2 fixation, soil). Data from Nyfeler *et al.*, 2011.

and other benefits can best be targeted at the farm scale. Indeed, most farms keep animals that differ in energy and protein demand (animals of various growth or lactation stages, sometimes various species or breeds). For example, too intensive feeding of replacement heifers can impair milk production later on (Sejrsen and Purup, 1997). In addition, adapted hardy breeds can be fed on low-quality forage and valorise marginal lands or infrequently defoliated fields by producing valuable meat products (Zehnder *et al.*, 2017). Thus, prioritising forage quality on the area needed for the most demanding livestock and other benefits on the remainder may be an efficient trade-off.

Biodiversity conservation

Some grasslands are among the communities with highest plant species richness, if small scales up to 50 m^2 are considered (Wilson *et al.*, 2012). Recurring disturbance by mowing or grazing is thought to reduce the asymmetry of competition and benefit the coexistence of many plant species (Zobel, 1992). Permanent grasslands also shelter high plant genetic diversity and are a valuable resource for breeding endeavours (Boller *et al.*, 2009). High plant diversity usually promotes diversity at higher trophic levels, although correlations among taxonomic groups are sometimes weak (Lüscher *et al.*, 2015). Moreover, the turnover of stubble and roots sustains complex food webs in grassland soils (Creamer *et al.*, 2016).

Despite the high potential of grasslands for biodiversity, agricultural grasslands are often relatively species poor and populated by ubiquists (Aviron *et al.*, 2009) due to competitive exclusion of specialist species following an increase in nutrient availability (Foster and Gross, 1998). A review by Humbert *et al.* (2016) pointed out that the amount and duration of N addition act additively on reducing plant species richness. Frequency and timing of harvest operations have a major impact on the faunal communities (Buri *et al.*, 2013). Thus, at the field scale, there is a clear antagonism between management intensity and biodiversity (Dumont *et al.*, 2016). A number of specific measures have been suggested to sustain biodiversity at the field scale. First, plant species may be directly added to existing swards. The success of these interventions depends on site conditions, the propagule material and sward management after addition (Kiehl *et al.*, 2010). Adding legumes can benefit both pollinator populations (Williams and Osborne, 2009) and grassland productivity (Teixeira *et al.*, 2015). In any operation of seed addition, care must be taken on its effect on composition and genetic diversity of the native vegetation (Schröder and Prasse, 2013). Secondly, invertebrate diversity can be helped by adjusting mowing time to target species (Buri *et al.*, 2013; Sabatier *et al.*, 2015) by the creation of uncut refuge areas for mobile organisms (Buri *et al.*, 2013) and by avoiding rotatory machinery such as conditioner or flail mowers (Humbert *et al*., 2009). Third, extensive grazing creates an uneven vegetation structure, i.e. various ecological niches, which may favour faunal diversity (Sabatier *et al*., 2015). A prime example for high niche diversity are wooded pastures. Scattered trees produce a fine mosaic of gradients in terms of light, microclimate, soil nutrient, moisture, food availability, and even of disturbance caused by uneven use of space by livestock (Moreno *et al*., 2016). The spatial heterogeneity of wooded pastures contributes to a higher diversity of multiple taxa compared to other adjacent land uses (Plieninger *et al*., 2015). Moreover, as a mixture of forest and grasslands, wooded pastures often conserve a specialised set of species.

At the farm scale, increasing the heterogeneity of grassland management in space and time may benefit biodiversity without impeding overall productivity (Sabatier *et al*., 2015). This has been shown for a rotational grazing system with the exclusion of one paddock from grazing for two months during the main flowering period (Ravetto Enri *et al*., 2017). Huguenin-Elie *et al*. (2014) compared model farms managing the same number of mountain grasslands but with contrasting management heterogeneity among grasslands. The 'intensive bottom' farm (with 20 intensive grassland fields on the bottom of the valley) had a considerably lower total plant species richness than the 'extensive slopes' farm (with 20 extensive grassland fields on the valley slopes) (Table 1). Most importantly, the species richness of the 'four grassland types' farm (comprising of intensive and extensive grasslands on the bottom and slopes of the valley) was similar to the one of the 'extensive slopes' farm, although half of its grasslands were intensively managed. This is explained by the large β-diversity between grassland types. It should be noted that the location of the different grassland types should be taken into consideration to maximise habitat area and connectivity within and between farms (Kremen *et al*., 2007).

Climate change mitigation

Grasslands are key for climate change mitigation because of (1) the amount of carbon (C) stored in their soils, with 340×10^9 t C in the top meter, equivalent to half the atmospheric C (Conant *et al*., 2001; FAO, 2017), (2) the emission of greenhouse gases (GHG) such as N_2O from soil and CH_4 from ruminants associated to grassland-based farming, and (3) the sensitivity of GHG fluxes to farming practices (Soussana *et al*., 2004; Lal *et al*., 2015). Because it is easier and faster for soils to lose than to gain C, it is crucial to at least maintain these stocks (Smith, 2014). Grassland soils are net sinks of 0.60 ± 0.64 SD t C ha^{-1} yr^{-1} in Europe (Freibauer *et al*., 2004) and globally, C sequestration by permanent pastures could offset up to 4% of the global GHG emissions (Lal, 2004). Hence, C sequestration by grasslands could partly mitigate GHG emissions from livestock production. In nine European grasslands, C sequestration did offset 56% of the emissions of N_2O from soil and of CH_4 from enteric fermentation (weighed in CO_2e; Soussana *et al*., 2010). If accounting for the digestion of the harvested forage, the net GHG balance reached 0.1 t C-CO_2e ha^{-1} yr^{-1}, indicating a moderate net sink activity. In contrast, Chang *et al*. (2015) estimated a net sink of 0.15 ± 0.07 t C ha^{-1} yr^{-1} for European grasslands and identified

Table 1. Plant species richness at the field scale for four types of mountain grasslands and at the farm scale for three model farms, all with 20 grassland fields, but comprised of only one or of all four of the grassland types. At the farm scale, the species richness is the aggregated number of species. The model farms were constructed by randomly sampling fields within the corresponding grassland types (100 resampling per model farm; Huguenin-Elie *et al*., 2014).

Field scale	**Species richness**	**Farm scale**	
Grassland type		**Model farm**	**Species richness**
IB: Intensive, bottom of valley (n = 40)	31 ± 0.9	'intensive bottom': 20 × IB	110 ± 8.6
IS: Intensive, slopes of valley (n = 18)	40 ± 2.1	'extensive slopes: 20 × ES	175 ± 5.3
EB: Extensive, bottom of valley (n = 14)	40 ± 2.5	'2 grassland types': 12 × IB and 8 × EB	155 ± 8.9
ES: Extensive, slopes of valley (n = 35)	46 ± 1.7	'4 grassland types': 5 × each IB, IS, EB and ES	169 ± 9.3

grassland-based systems as a net source of GHG (0.5 t C-CO_2e ha^{-1} yr^{-1}) when N_2O, CH_4 and CO_2 from forage digestion were included. Grassland C balance largely depends on the current level of soil organic C (SOC) and C sequestration might be a saturating process (Castellano *et al.*, 2015). Drained organic soils may release large amounts of C (Soussana *et al.*, 2010). Tiemeyer *et al.* (2016) reported a mean source of 8.0 ± 4.7 t C-CO_2e ha^{-1} yr^{-1} for grasslands over peats and other organic soils.

Integrating trees in ruminant production systems favour C sequestration (Mutuo *et al.*, 2005; Franzluebbers *et al.*, 2017). The SOC content under wooded pastures is significantly higher than under tree-less pastures (Lorenz and Lal, 2014), and C is on average stored deeper and for longer (Howllet *et al.*, 2011a,b). Carbon stocks in Atlantic and Mediterranean wooded pastures are up to 30% higher than in neighbouring tree-less pastures (Howllet *et al.*, 2011a,b). On the contrary, woody encroachment of grasslands might lead to SOC losses on wet sites (Jackson *et al.*, 2002). Recurrent fires cause losses of soil organic matter from the upper soil layer (Lal, 2004; Wardle *et al.*, 2008). Thus, low fire-prone ecosystems such as sparsely wooded pastures can retain SOC for longer than fire-prone woody ecosystems in seasonally dry regions (Rigueiro-Rodríguez *et al.*, 1999; Ruiz-Mirazo *et al.*, 2011). An intermediate tree density therefore seems optimal for long-term C storage.

Carbon inputs to soil depend on grassland productivity, on the type and intensity of utilisation and on the form and amount of fertilisation (Soussana *et al.*, 2004; Jones and Donnelli, 2004). Grassland C sequestration peaks at intermediate management intensity (Ward *et al.*, 2016). Although there are divergent opinions on the effect of grazing on C sequestration, appropriate stocking rates and rotational grazing can potentially alleviate grassland degradation and increase C sequestration (Lal *et al.*, 2015). Erosion, frequently associated with overgrazing, is a major cause of SOC loss (Diamini *et al.*, 2016). Conant and Paustian (2002) estimated a potential C sequestration at a global scale of 45.7×10^6 t C yr^{-1} through rehabilitation of overgrazed pastures. Soussana *et al.* (2004) calculated a sustained GHG sink activity over five years only for low stocking rates with moderate N fertiliser inputs. This is in line with the results of Chen *et al.* (2015) who observed the highest SOC stocks under moderate grazing due to the largest root production and turnover. Grazing seems more beneficial than mowing for SOC storage up to a certain stocking rate (Rumpel *et al.*, 2015; Koncz *et al.*, 2017). At the field scale, Senapati *et al.* (2014) observed a six times larger net C storage under grazing than under mowing. In this experiment, however, the plant C excreted as dung by the livestock was not returned to the mown field.

Improved plant N nutrition increases C capture by the plants, which could benefit C sequestration. However, the positive effect of N fertilisation on the terrestrial C sink could, in terms of GHG balance, largely be offset by the resulting increase in CH_4 and N_2O emissions from the ecosystems (Liu and Greaver, 2009). In this respect, forage legumes could play a key role. First, they greatly reduce the need of N fertilisation, reducing the risk of N_2O emission and the CO_2 emitted during the production of mineral N fertiliser (Lüscher *et al.*, 2014). Second, legumes can reinforce the capacity of soils to accumulate organic C as observed with the establishment of biodiverse grass-legume permanent grasslands in Portugal (Teixeira *et al.*, 2015). In the arid and semi-arid regions of Portugal, soils are low in SOC and grasslands are typically low yielding and susceptible to fire-prone shrub encroachment. After replacement of the semi-natural grasslands with biodiverse grass-legume pastures, yields can increase twofold (Teixeira *et al.*, 2015) and SOC content increases by 2.4 t C ha^{-1} yr^{-1} during the first 10 years (Teixeira *et al.*, 2011). Finally, condensed tannins, frequent in legumes, can reduce enteric CH_4 emission (Mueller-Harvey *et al.*, 2017).

Mitigating climate change through SOC sequestration is synergetic with agronomic benefits, like increased cation exchange capacity, soil fertility and water holding capacity, and decreased erosion (Conant and Paustian, 2002). SOC is hence favouring the provision of multiple ESS (Lal *et al.*, 2015).

However, synergies can transform in antagonisms along the gradient of management intensity. For instance, while C sequestration and biodiversity conservation are both favoured by an intermediate rather than an intensive management, a further extensification supports biodiversity more but may reduce C sequestration. Also, C sequestration promoted by increasing plant productivity and/or tree cover could reduce water yield (Huxman *et al*., 2005; Kim *et al*., 2016).

Regulation of nutrient cycles

The effects of grassland management, fertilisation or grazing on the nutrient cycles have been dealt with in comprehensive reviews (e.g. Vertès *et al*., 2018). Here we focus on the effects of the botanical composition. With respect to N, reaping the benefits of SNF by legumes is a key factor to increase N efficiency (harvested N/fertiliser N) in forage production. There is mounting evidence that this is better achieved with multispecies grass-legume mixtures than by sole cropping of legumes (Lüscher *et al*., 2014). With grass-legume leys, the legume species and their relative abundance in the seed mixtures can be aligned to the targeted performances. Legume persistence is often poor in such mixtures (Brophy *et al*., 2017), but this may only be a minor drawback for short-term leys (three years or less), because (1) a legume abundance as low as 30% suffices to achieve very high N efficiency (Suter *et al*., 2015) and (2) the initial legume abundance still positively influences forage yield during the year following a strong decline in legume abundance (Brophy *et al*., 2017). However, keeping a sufficient legume abundance for high N input from SNF in permanent grasslands is a major challenge (Phelan *et al*., 2015). Regular grassland reseeding to rectify legume abundance might offset the benefits of legume-generated fertiliser savings in terms of emissions of reactive N forms. Indeed, depending on the method used and its timing, grass-to-grass reseeding can generate high NO_3^- (Conijn and Taube, 2004) and N_2O (Reinsch *et al*., 2018) losses. Moreover, Necpálová *et al*. (2013) observed on a soil containing 4.5% organic C, that the loss of total soil N following grassland renovation after ploughing in summer was in the range of 3000 kg N ha^{-1}. Around 20 years would be necessary for this N amount to be symbiotically fixed by a mixed sward (estimation based on 25% legumes and a yield of 10 t DM ha^{-1} yr^{-1}). Overseeding instead of reseeding would help conserve N in the soil. Benefits of overseeding legumes on livestock weight gain have been shown (Graves *et al*., 2012; Del Pino *et al*., 2016), albeit short-lasting, but this method is quite unreliable (Phelan *et al*., 2015). Improved strategies to manipulate legume abundance in permanent grasslands are therefore needed. Such strategies should include endeavouring to favour legume overwintering like cultivar selection and management optimising legume leaf area in late autumn (Lüscher *et al*., 2001).

Whether the substitution of fertiliser N by SNF maintains or reduces N leaching from grasslands is still contentious (Lüscher *et al*., 2014; Phelan *et al*., 2015). However, at a minimum, for a similar level of N inputs (fertiliser + SNF), grass-legume mixtures improve crude protein yield without increasing N leaching compared to sole grass cropping (Nyfeler, 2009). There is some evidence that, in grass-legume mixtures, the companion grass is able to significantly reduce the leaching of inorganic N but not of dissolved organic N leaking from the legumes as compared to legume sole-crops (Kušlienė *et al*., 2015). There are indications from the biodiversity experiment in Jena that working with higher levels of plant diversity could help reduce leaching of dissolved organic N (Leimer *et al*., 2016). The number of species and the functional traits that would assist in that respect in productive grasslands are yet to be determined.

In addition to the complementarity between fixing and non-fixing species, complementarities in rooting depth or timing of N uptake may further improve N capture by multi-species swards under various climates (Joffre, 1990; Husse *et al*., 2017). Thus, combining species differing in multiple features may further improve N capture by grass-legume mixtures. Intraspecific variability might also contribute to asynchronous N uptake, as large differences in precocity exist among varieties. This hypothesis is supported by the observed positive effects of genetic diversity (Prieto *et al*., 2015). With respect to N efficiency, positive interactions appear more consistent between legumes and grasses than between legumes and forbs (Husse *et al*., 2017) or grass-legume and forbs (Cong *et al*., 2017). How much plant diversity itself affects N dynamics in the soil as compared to the presence of specific functional groups is still under debate (Mueller *et al*., 2013). Species developing a large and deep root system may also influence nutrient cycling by affecting soil hydrology. Macleod *et al*. (2012) observed a significant decrease in water runoff caused by the stronger root growth of a *Festulolium* cultivar as compared to *Lolium perenne*. Such traits would be particularly useful for grasslands having a critical location along the hydrological pathways (Gascuel-Odoux *et al*., 2009). Finally, plant traits can indirectly affect nutrient cycling by shaping soil microbial communities. Differences in root exudation might underlie these effects (Kaštovská *et al*., 2015) and plant species might interact with each other with respect to their influence on the soil microbial community (Zhao *et al*., 2017).

Evaluation of ESS from the field to the landscape scale

Multi-criteria evaluation of ESS

Synergies among ESS have been shown with biodiverse, legume-rich permanent pastures that enhance regulation and maintenance ESS (soil quality, C stocks, N availability) as well as provisioning ESS (Teixeira *et al*., 2015). However, ESS can be antagonistic to one another (Bennett *et al*., 2009; sections 2.2 to 2.4) thus, optimising the provision of multiple ESS requires a multi-criteria assessment followed by the development of trade-offs adapted to each individual situation (Howe *et al*., 2014). In agriculture, trade-offs have to also consider the supply of goods from the systems. For instance, it is well established that functional plant diversity can enhance provisioning ESS, but the supply of goods from grassland-based systems is greatly enhanced by agricultural intensification, which usually negatively affect plant diversity. Therefore, optimally, multi-criteria evaluations would assess both the level of provisioning ESS and the supply of goods. Unfortunately, grassland performances are often assessed based on the supply of goods alone because not enough data are generally available to quantitatively disentangle provisioning ESS from total yield.

Ultimately, trade-offs are worked out by farmers and decision-makers but they should be aided by decision support tools. One multi-criteria assessment method is Life Cycle Assessment (LCA). LCAs assess the environmental impacts of a good throughout its life cycle, from extraction of raw material to disposal (Hellweg and i Canals, 2014). While their initial focus was on the negative impacts of production rather than on ESS, impact assessment models in LCA are nowadays moving towards assessing ESS together with environmental damages (Othoniel *et al*., 2016; Nemecek *et al*., 2016). Although the field is still hindered with issues such as a lack of time-dependency of effects, as well as clear models of interrelationships among impacts, much progress has recently been made. There are now several LCA models to evaluate effects of the agricultural management on biodiversity (Teixeira *et al*., 2016) or soil quality (Legaz *et al*., 2017), in particular looking at SOC depletion and its influence on production (Morais *et al*., 2016). The main advantage of the LCA method is a unified, consistent framework to assess not only farm-level ESS, but also whole-chain ESS of any farm product. The quantification of the impact of entire production chains on ESS is nevertheless still subject to large uncertainties. A further remaining challenge with the evaluation of grassland-based systems is the fair consideration of the potential of the site for the cultivation of crop for direct human consumption (van Zanten *et al*., 2016) and of its carrying capacity.

In LCA, indicators are often weighted into aggregated results to facilitate decision-making. For instance, the aggregated indicator by Cao *et al*. (2015) quantifies the role of land use on six provisioning and regulating ESS: biotic production, fresh water recharge, erosion resistance, mechanical and physicochemical water filtration and climate regulation potential. The ESS are modelled in biophysical units and converted into monetary units based on economic valuation of ESS reduction. Monetary and non-monetary valuation of ESS are complicated by the still imprecise quantification of the ESS and by the patchy information available to the stakeholders about the gains associated with ESS (Costanza *et al.*, 2017). Although aggregated indicators can be helpful, they carry the risk of leading to decisions that fail to take the specificities of each situation into account. Indeed, the importance, respectively the valuation, of the different ESS clearly differs across situations (Bernués *et al.*, 2015). LCA models aggregate results using default weighing factors for each indicator or more advanced integration methods such as fuzzy logic (Agarski *et al.*, 2016). Another option is to weigh ESS using subjective and context-dependent value judgments of multiple stakeholders (Garrido *et al.*, 2017). Such participatory processes may only be locally applicable, but that may turn into an advantage. It means that when faced with the same trade-offs, different experts may decide, depending on the local conditions, which ESS should take priority and solve potential conflicts.

Mathematical methods to simultaneously analyse multiple ESS at the field scale have recently been developed (Dooley *et al.*, 2015). But much work remains to be done, as the evaluation of some ESS requires cross-scales analyses (Duru *et al.*, 2018). To our knowledge, few studies have assessed the effect of grassland management on multiple ESS. Pan *et al.* (2014) used the balance between grazed and total primary production to discuss antagonisms between meat production, C sequestration and water conservation. However, they did not consider changes in grassland productivity due to management changes. Dumont *et al.* (2016) discussed options to improve the delivery of multiple ESS by livestock production systems and highlighted large differences in ESS delivery among production systems. Yet, the main scale of their analysis was the whole production system and management options at the grassland level were not analysed for multiple ESS simultaneously.

Landscape scale evaluation of ESS

ESS can be supplied at different spatial scales and the beneficiaries of the ESS vary with the considered scale (e.g. local population for water quality regulation, the whole society for climate change mitigation). The landscape is one of the important scales to consider for studying ESS. For ecologists, a landscape is the level of ecological organisation characterised by a specific arrangement of ecosystems (Burel and Baudry, 1999). In social sciences, a landscape is rather considered as a social construction as perceived by a group and produced by economic and cultural practices (Bertrand and Beruchavili, 1978). It thus has a perceptive, aesthetical meaning. Its spatial structure reflects the relations between societies and their environment (Burel and Baudry, 1999). Studying the supply of ESS at the landscape scale is crucial for three main reasons. First, ESS supply by grasslands not only depends on field-scale parameters, but also on farm-scale management (i.e. other available fields, farm structure and strategy) and on the surrounding landscape elements. For instance, ESS with respect to water regulation or pollination depend on the position of the grasslands along the hydrological pathways or within the habitat network, respectively (Kremen *et al.*, 2007). Moreover, relationships between ESS vary across a landscape because of differences in land use and pedo-climatic conditions within this landscape (Li *et al.*, 2017). Second, some ESS, such as recreational opportunities, aesthetic enjoyment or spiritual benefits are mostly generated at the landscape scale (Harrison *et al.*, 2010; Fagerholm *et al.*, 2016). These cultural ESS are very important in grassland-dominated landscapes (Garrido *et al.*, 2017). Grassland landscapes are usually appreciated, for they are perceived more natural than cropland landscapes (Bugalho and Abreu, 2008). In addition, a heterogeneous agricultural landscape is generally more appreciated than less diverse landscapes (Hahn *et al.*, 2017). Third, as a consequence of the two first points, the landscape, interface between the society and its environment, constitutes a privileged scale to incorporate ESS in management strategies and decision making that include a large spectrum of stakeholders (farmers, other economic branches bounded to nature, authorities, citizens), especially through quantifications and mapping procedures.

Quantifying, valuing and mapping ESS is seen as a way to support policy making (Daily and Matson, 2008), especially for the evaluation of trade-offs (Farber *et al.*, 2002). In order to optimise grasslands

ESS supply, landscape-scale spatial analyses are crucial for two main reasons. First, they help to identify hotspots of ESS supply (Figure 2), allow depicting transition areas between grasslands and non-farm habitats (Figure 2), and support the prioritisation of management objectives considering spatially more nuanced criteria. This provides baselines for adjustments of agricultural policies and incentives. Second, they may take into account the structure and features of the landscape (e.g. diversity, openness, connectivity or fragmentation) that affect some ESS and need to be considered in political programs (e.g. financial support of the Swiss federal and regional authorities to implement habitat connectivity measures). Such programs are, however, difficult to evaluate with respect to their effects on multiple ESS (Angelone and Holderegger, 2009) and only few scientific studies have yet considered the potential of landscape-scale approaches on ESS supply (Hodder *et al.*, 2014). Nevertheless, this field is developing quickly. Li *et al.* (2017) for instance, presented a method for the evaluation of the relationship between two ESS at the landscape scale. This method is based on a spatially explicit quantification of multiple ESS at the landscape scale, followed by a pairwise overlay of the ESS on each pixel and a partial correlation analysis. Such approaches will greatly support the evaluation of multiple ESS at larger scales.

Conclusion

Management intensity is a major driver of the delivery of goods and ESS from grasslands. From the available body of literature, we conclude that the supply of goods, C storage and biodiversity conservation have their optimum at different levels of grassland intensification (Figure 3a). Hence, these ESS can generally not all be maximised on the same individual field. At the field scale, various specific options exist to improve the delivery of individual ESS. Some of these options can be beneficial to several ESS simultaneously, like promoting an optimal plant functional diversity, and can be combined. For instance, planting trees to promote C storage, keeping uncut refuges for biodiversity and establishing N_2-fixing legumes could be combined within a single field (Figure 3b). An optimal legume abundance in the sward seems particularly promising to favour multiple ESS. Nevertheless, none of these options allow for alleviating the conflicts occurring along the intensification gradient and at the field scale, an intermediate intensity implies mediocre performances for both biodiversity conservation and the production of high-quality forage (Figure 3a, 3b). The current state of evidence indicates that this challenge must be addressed at the farm or landscape scale. By combining various management intensities and targets involving different types of grasslands at the farm scale (Figure 3c), it seems possible to better reconcile production with biodiversity conservation and pollination than by uniformly managing all fields of the farm at intermediate level of intensity (Figure 3d). We conclude that multiple ESS by grassland-based systems can be optimised by combining 1) specific improvement measures at the field scale with 2) heterogeneity

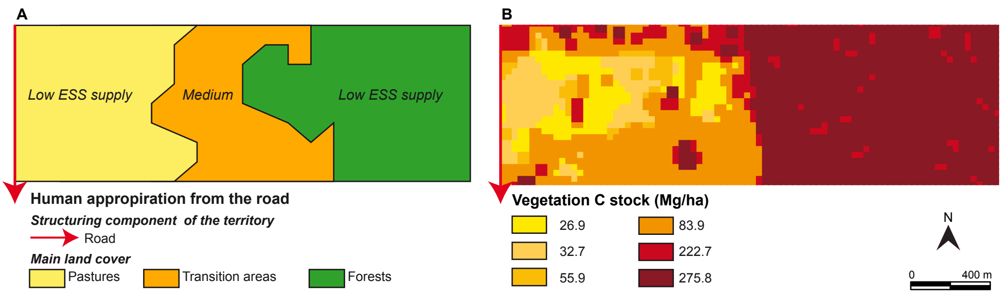

Figure 2. Spatial structure of ESS indicators in a 200 ha landscape of the Brazilian Amazon (landscape including two farms). A gradient in ESS supply can be distinguished from the road, which is the central axis of deforestation. (A) General trend for 6 ESS indicators based on statistical modelling using remote sensing and field data and (B) for the same landscape, detailed mapping of vegetation carbon stock. Adapted from Le Clec'h (2017).

among grassland types at the farm or landscape scale. This heterogeneity would target the right balance between fields managed at very low, intermediate and high intensity, and optimise the spatial location of the different grassland types in accordance with the surrounding nonfarm habitats (Figures 3c and 3d). The high intensity must, of course, remain within the carrying capacity of the site. For C storage, this strategy might be less favourable than an intermediate intensity over the whole farm area, but would allow the integration of optimal elements, like wooded pastures of intermediate management intensity, grazed for instance by replacement heifers. Multi-criteria evaluation tools to quantify ESS and weigh antagonistic services are currently being refined. Methodological advancement in this field is critical to develop multi-scale strategies for multiple ESS.

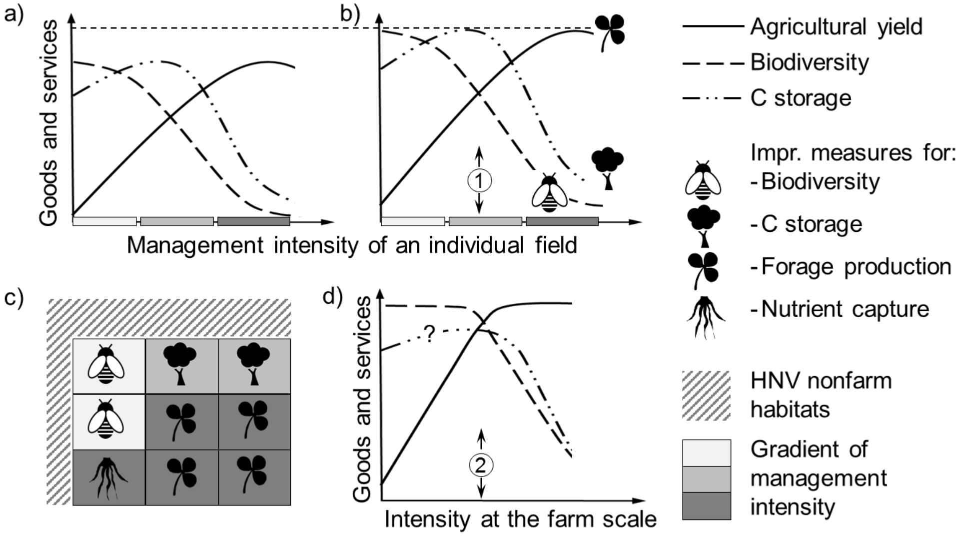

Figure 3. Schematic summary of the effects of grassland management intensity on the delivery of goods and services (a) at the field scale without specific measures, (b) at the field scale with improvement measures, and (d) for the average intensity at the farm scale. Panel (c) illustrates the concept of grassland heterogeneity at the farm scale combined with specific measures at the field scale, which might result in improved multifunctionality for an intermediate average level of intensity at the farm scale (panel d). The main target for each field takes the surrounding nonfarm habitats into consideration (HNV: high nature value). At the field scale, an intermediate intensity level promotes C storage but performs quite poorly in term of agricultural yield and biodiversity. This is expected to be similar for a farm having all its fields uniformly managed at intermediate intensity. A farm combining extensive to intensive grasslands (panel c) has an intermediate average level of intensity at the farm scale but maintains fields of high biodiversity (extensive grasslands), intermediate grasslands for C storage and grazing of less demanding livestock and fields for the production of energy- and protein- rich forage (intensive grasslands). Such a farm would, therefore, supply multiple ESS.

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A meta-analysis on the impacts of climate change on the yield of European pastures

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Abstract

Significant climatic changes are predicted across Europe, some of which are already occurring. These changes will vary dramatically across the continent, with very different conditions expected in the north than in the south. This study assesses the impacts of elevated atmospheric CO_2 concentration (+C), increased air temperature (+T) and changes in water availability on pasture yield and makes region-specific predictions of future pasture conditions. The yield measure used is above ground dry weight and is evaluated across pasture and forage species from different plant functional groups. The results of the meta-analysis showed that +C will increase plant growth across Europe, with shrubs experiencing a larger increase than other functional groups. Increased temperature (+T) will increase plant growth in Alpine and northern areas but will decrease it in continental Europe. Droughts will cause significant reductions in growth everywhere except for Alpine areas. The results demonstrate what can be expected from future pastures and can help European livestock farming systems to address the challenges presented by climate change.

Keywords: climate change, yield, pastures, CO_2, temperature, water availability

Introduction

Climate change is predicted to bring significant changes to Europe. Temperatures will rise across the continent, particularly in the south in summer and in the north-east in winter (EEA, 2017). Total annual rainfall will increase in the north and decrease in the south and all areas will continue to experience rising atmospheric CO_2 concentrations for some time to come (EEA, 2017). These changes will have significant impacts on vegetation and the livestock grazing on it. These impacts will vary across different European regions and across plant functional groups (PFGs). This study aims to quantify impacts of climate change on plant yield to determine the expected changes in forage availability in the years to come. This will be done through a meta-analysis of changes in aboveground dry weight (AGDW) under elevated atmospheric CO_2 concentrations (+C), increased air temperature (+T), changing water availability (+W and –W), encompassing regional variability and the effect of PFG.

Materials and methods

A systematic review was conducted to find studies for the meta-analysis. Sources used were the Web of Science database, grey literature, studies used in previous meta-analyses and bibliographies of key review articles. To be included, the studies had to meet the following criteria:

- takes place in Europe, or in laboratory conditions representative of a European climate;
- includes a common European forage species;
- tests the effect of +C, +T, +W and/or –W on plant aboveground dry weight (AGDW);
- provides means, standard deviations (or equivalent) and sample sizes.

Altogether, 144 studies were selected for inclusion with a total of 998 observations. The average +C treatment was +284 ± 79 μmol mol^{-1} (mean ± sd), for +T it was +3.2 ± 1.7 °C, for +W experimental treatments had 117 ± 96% more water than control treatments, and for –W experimental treatments had 79 ± 26% less water. These +C and +T treatments are representative of average predicted climatic changes, while the +W and –W treatments are indicative of especially wet or dry seasons.

Plant species were grouped by PFG; the vast majority were perennial with a C3 photosynthetic pathway. The studies were grouped into five geographic regions (Alpine, Atlantic, continental, northern and southern). The natural logarithm of the response ratio was chosen as the effect size for the analysis, as described by Hedges *et al.* (1999). A fixed effects model was used, with the choice of effects determined through ANOVA (GenStat) and the model was implemented using Markov Chain Monte Carlo simulations in WinBUGS. Analyses were performed where data from at least five studies was available; this occasionally meant that some regions had to be grouped together. Results were also grouped when region or PFG did not have a significant effect.

Results and discussion

There was increased AGDW under +C conditions, though considerably more so for shrubs than for other PFGs (Table 1).This is consistent with the results of Ainsworth and Long's (2004) meta-analysis, but not with those of Poorter and Navas (2003), who found that faster-growing plants had a stronger response than slower-growing ones, or of Wang *et al.* (2012), who found that herbaceous plants exhibited a (not significantly) greater increase in AGDW than woody species. This variation in meta-analysis results is surprising and suggests that perhaps a different factor, e.g. the identity of the species, is having a stronger effect than PFG. For +T, shrubs also exhibited a different response to other PFGs, their production decreased while increasing for all other plant types. This may be related to competition effects as very few of these studies involved monocultures; however we cannot be sure of this and the literature is contradictory (van Wijk *et al.*, 2004). Under –W, there was no significant difference between PFGs.

The increase in AGDW under +C was similar across all European regions (Table 2). Under +T, there was a large increase in the Alpine and northern regions, no significant change in the Atlantic region and a considerable decrease in the continental region. These results are to be expected. Those areas which are temperature-limited benefit from a warmer climate, while those which may already be experiencing overly high temperatures in summer will see yield reductions. While there was insufficient data to perform

Table 1. Percentage change in above ground dry weight under +C, +T and –W conditions for different plant functional groups. Values are mean ± standard deviation.

Functional group	+C	+T	-W
Shrubs	76.1 ± 19.2	-16.4 ± 10.0	-19.6 ± 4.7
Forbs	13.2 ± 6.7	24.6 ± 12.6	
Legumes	9.0 ± 4.5	17.3 ± 16.4	
Graminoids	1.1 ± 3.5	13.5 ± 10.1	

Table 2. Percentage change in above ground dry weight under +C, +T, –W and +W conditions for different European regions. Values are mean ± standard deviation.

European region	+C	+T	-W	+W
Alpine	11.9 ± 4.4	82.9 ± 18.5	-13.2 ± 7.8	57.1 ± 19.9
Northern			N/A	
Continental		-32.6 ± 7.6	-42.4 ± 5.4	
Atlantic		-11.7 ± 7.7	-31.3 ± 5.4	No data
Southern		Insufficient data	-29.5 ± 7.0	N/A

an analysis for the southern region, this would suggest a reduction in AGDW in the future, which is consistent with the literature (Rötter and Höhn, 2015). All areas will experience yield reductions under –W conditions, with the smallest loss in the Alpine region, which is not generally water-limited. Curiously, the southern region is predicted to undergo a lower reduction in AGDW than either the Atlantic or continental regions. This may be because plants in the southern region are already partially adapted to drought conditions (Volaire *et al.*, 2009). For +W conditions, there was an increase in AGDW in regions likely to experience elevated rainfall, though with a very high degree of variance. It should also be noted that while precipitation is predicted to increase in northern Europe, heavy-rain events are expected to become more frequent and the risk of damage to plants through water-logging will increase.

Conclusion

While some areas, particularly northern Europe, can expect improved pasture yields, other regions will experience reductions in AGDW. It will likely become increasingly necessary for farmers in southern and continental Europe to irrigate their pastures during dry periods, or if this is not feasible then it may be that livestock production will need to adapt, consider different species and breeds or move to other areas. With different PFGs responding to the changes in different ways it is also likely that pasture compositions will be altered. All of these changes will have implications for livestock productivity and welfare.

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Impact of climate change on grass growth at two sites in Ireland

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Abstract

The MoSt grass growth model was used in conjunction with the group 6 WRF EC-Earth forecast model to predict the change in grass growth between 1986-2000 and 2031-2060. The future weather projection period is composed of two different emission scenarios, a low-medium emission and a high emission. Grass growth and N leaching predictions were obtained using the weather projection for two locations in Ireland (Moorepark (south) and Ballyhaise (north)) and for two soil types: heavy soil or free draining soil. Overall, the simulations show that, in the future, grass growth will start slightly earlier in the year but will reduce during the summer period. This reduction is more pronounced in the high emission scenario than in a low-medium emission scenario and is highly dependent on soil type. It is complicated to draw definitive conclusions from this work due uncertainty associated with simulation of future weather; however, it does highlight the increase in variation between years which will lead to a more complex grazing management due to fewer 'standard' years.

Keywords: grass growth, climate change, model, nitrogen leaching, prediction

Introduction

Weather conditions in Ireland are generally favourable for grass growth. As a result, dairy farming in Ireland depends to a large extent on the efficient conversion of grass to milk as grazed grass is the cheapest feed available on most dairy farms. The main factors influencing grass growth are climatic conditions, soil type and soil reserves of nutrients such as nitrogen (N). However, due to climate change the weather could become less favourable for grass growth. The utilisation of a grass growth model combined with predicted weather conditions is the best way to predict the impact of climate change on grass growth in the future.

Materials and methods

The Moorepark St Gilles Grass Growth (MoSt GG) model (Ruelle and Delaby, 2016) was used to predict grass growth up to 2060 using the weather forecast model projection for Ireland from the Environmental Protection Agency (group 6 WRF EC-Earth, resolution 6 km (Nolan, 2015) (called WRF hereafter)). In the WRF simulations, the future period 2021-2060 is compared with the past period 1981-2000. Here, we analysed three 15 year periods - 1986-2000, 2031-2045 and 2046-2060. When analysing climate change signals it is important to compare future simulations with past simulations using the same model and not future simulations with past observations. All models have biases, so comparing past with future simulations ensures that the differences found are not due to biases of the model. Within the WRF simulations, two different scenarios are presented: a low-medium (L-M) emission scenario and a high (H) emission scenario. Emissions are defined as representative concentration pathway scenarios focused on radiative forcing (Nolan, 2015). Radiative forcing is the change in the balance between incoming and outgoing radiation via the atmosphere caused primarily by changes in atmospheric composition. In this study the forcing values for the year 2100 or after were 4.5 and 8.5 W.m^2 for the L-M and the H emission scenarios, respectively. Data from the WRF simulation were extracted for two sites: Moorepark (Mpk) Co. Cork (52.2N; -8.3W) and Ballyhaise (Bal), Co. Cavan (54.1N; -7.3W) and are summarised in Table 1. Overall, for both sites, average annual temperature will increase between 1 and 1.5 °C between

Table1. Average (and standard deviation) main traits of the WRF weather.

	Emission[1] level	Year	Mean temperature (°C)	Total yearly rainfall (mm)	Total yearly radiation (J cm^{-1})
Ballyhaise		1986-2000	8.2 (0.6)	1,184 (134)	997 (33)
	Low-Medium	2031-2045	9.2 (0.4)	1,146 (162)	998 (36)
		2046-2060	9.3 (0.4)	1,056 (162)	986 (38)
	High	2031-2045	9.4 (0.5)	1,110 (151)	987 (38)
		2046-2060	9.6 (0.4)	1,062 (146)	965 (40)
Moorepark		1986-2000	9.0 (0.5)	1,204 (206)	1,050 (26)
	Low-Medium	2031-2045	10.0 (0.4)	1,160 (212)	1,051(37)
		2046-2060	10.1 (0.5)	1,046 (168)	1,050 (36)
	High	2031-2045	10.2 (0.5)	1,156 (162)	1,044 (41)
		2046-2060	10.5 (0.5)	1,067 (160)	1,038 (38)

[1] Emissions are defined as representative concentration pathway scenarios focused on radiative forcing.

the years 1986-2000 and 2046-2060; however, the yearly rainfall and radiation will remain stable. Two contrasting soil types were evaluated - a free draining soil (FDS) (sand 22%, clay 26% and organic matter (OM) 7%) and a heavy soil (HS) (sand 13%, clay 47% and OM 2.31%). An average of 200 kg N ha^{-1} y^{-1} was applied, a grazing event was implemented when the grass height reached 8 cm. The variation in terms of grass growth, N leaching, and grass growth pattern were evaluated.

Results and discussion

On average across all simulations, the Mpk weather resulted in higher cumulative grass growth (+454 kg DM ha^{-1} y^{-1}) than the Bal weather (Table 2). Similarly, the FDS had higher grass growth (+3,350 kg DM ha^{-1} y^{-1}) than the HS across all simulations. The Mpk and Bal weather resulted in similar leaching (average 113 kg N ha^{-1} y^{-1}), while the FDS resulted in higher leaching (+40 kg N ha^{-1} y^{-1}) than the HS (Table 2). Grass growth was always greater in 2031-2045, ranging from +17 kg DM ha^{-1} y^{-1} for the Mpk weather HS L-M emission simulation to +814 kg DM ha^{-1} y^{-1} for the Bal weather FDS H emission compared to 1986-2000. The H emission resulted in a greater increase in grass growth between these two periods (+452 kg DM ha^{-1} y^{-1} compared to +350 kg DM ha^{-1} y^{-1} for the L-M emission). The 2031-2045 simulation always resulted in a small decrease in N leaching (-4 to -10 kg N ha^{-1} y^{-1}), due to the absence of variation in the prediction of the total yearly rainfall.

The comparison of the simulations between 2031-2045 and 2046-2060 was more challenging. The H emission scenario always resulted in a reduction in grass growth ranging from -402 kg DM ha^{-1} y^{-1} for the Bal weather and the FDS to -705 kg DM ha^{-1} y^{-1} for the Bal weather and the HS. For the L-M emission simulation, 2046-2060 had greater grass growth than 2031-2045 for the HS simulation (average of +184 kg DM ha^{-1} y^{-1}) but resulted in lower grass growth with the FDS (-237 kg DM ha^{-1} y^{-1}). Although the simulations show that the variation in grass growth is highly dependent on soil type, weather location and emission scenario, an important conclusion is that the standard deviation in terms of grass growth always increases when comparing the year 1986-2000 (average SD of 1,050 kg DM ha^{-1} y^{-1}) to the year 2046-2060, especially for the H emission scenario (average SD of 1,391 kg DM ha^{-1} y^{-1} for the L-M scenario and 1,529 kg DM ha^{-1} y^{-1} for the H emission scenario) (Figure 1). In terms of the shape of the grass growth curve, the same tendency was observed for each soil type and weather scenario (not illustrated). The simulations predict an earlier start to the grazing season and a higher grass growth peak in the future. Summer grass growth is reduced, especially for the H emission simulation.

Table 2. Predicted annual grass growth (standard deviation) simulated using the group 6 WRF EC-Earth prediction forecast for Moorepark and Ballyhaise locations, with either a heavy (HS) or a free draining soil (FDS) for a low-medium (L-M) or a high (H) emission level.

	Weather	**Ballyhaise**		**Ballyhaise**		**Moorepark**		**Moorepark**	
	Soil type	**FDS**		**HS**		**FDS**		**HS**	
	year\emission level	**L-M**	**H**	**L-M**	**H**	**L-M**	**H**	**L-M**	**H**
Cumulative grass	1986-2000	11.6 (1.0)		8.8 (1.0)		12.4 (1.1)		9.2 (1.1)	
growth (t DM	2031-2045	12.3 (1.1)	12.4 (1.0)	9.0 (1.2)	9.1 (1.2)	13.0 (1.1)	13.0 (1.3)	9.2 (1.3)	9.3 (1.4)
ha^{-1} y^{-1})	2046-2060	12.1 (1.1)	11.8 (1.2)	9.0 (1.5)	8.7 (1.5)	12.9 (1.4)	12.3 (1.5)	9.5 (1.7)	8.6 (1.9)

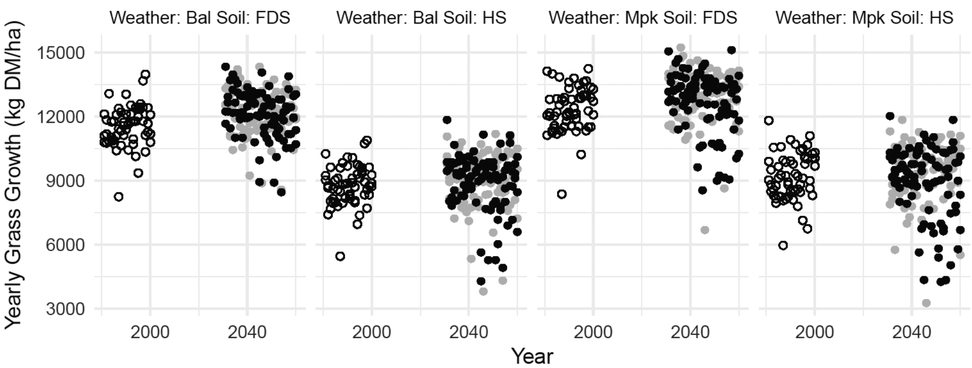

Figure 1. Predicted annual grass growth simulated using the group 6 WRF EC-Earth with a low medium (grey) or high (black) emission prediction forecast for the locations Moorepark (Mpk) and Ballyhaise (Bal) on an heavy (HS) or a free draining (FDS) soil.

Conclusion

The MoSt grass growth model can be used to predict future grass growth across different locations and soil types. Although it is difficult to draw definitive conclusions from this study, it is clear that the variation in grass growth between years will increase in the future, especially in high emission scenarios. In the future, Irish farmers will be challenged with higher grass growth variability between years.

Acknowledgements

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Life cycle assessment of grassland-based dairy production systems in Switzerland

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Abstract

The feeding system of dairy cows can strongly influence their environmental impacts. We compared three grassland-based production systems: (A) full-grazing with seasonal calving, and indoor feeding of fresh herbage with (B) reduced concentrate (< 500 kg cow^{-1} yr^{-1}), and (C) standard concentrate (800 - 1,200 kg cow^{-1} yr^{-1}) supplementation. The three systems were analysed on 12 pilot farms (PF) (four per strategy) in 2014 as well as on the experimental farm (EF) of the centre for Nature and Nutrition in Hohenrain (2014 - 16) with the life cycle assessment (LCA) method Swiss Agricultural LCA (SALCA). In terms of environmental impacts, higher concentrate inputs (C) resulted in higher P and K resource use, deforestation and ecotoxicity per kilogram of energy corrected milk (kg ECM). Full grazing tended to a higher global warming potential per kg ECM. However, the differences in environmental impacts per kg ECM were often larger between the single PF and the years than between the three systems. Four main factors influencing the environmental impacts were identified: (1) composition of the feed ration, (2) performance of the system (feed conversion ratio), (3) grazing and manure management, (4) purchase of animals.

Keywords: LCA, environment, dairy, production, grass, feed

Introduction

The choice of the feeding system in dairy production (i.e. grazing vs indoor, grassland vs maize/ concentrate based feeding) can strongly influence environmental impacts. Different life cycle assessment (LCA) studies have investigated this topic; however, due to the multitude of the influencing factors, they came to partly contradictory conclusions (Nemecek and Alig, 2016; Nemecek *et al.,* 2014). In a previous system comparison, the full-grazing system tended to perform better per kg ECM in terms of eutrophication, acidification, ecotoxicity, resource use (K and P) and deforestation than the maize/ concentrate based system, which itself reached more favourable values categories land-use, global warming potential and ozone formation (Sutter *et al.*, 2013). In Switzerland, however, most dairy farms practice a combination of partial grazing with indoor feeding of fresh herbage and concentrate supplementation, the environmental impacts of which have not been examined in detail by LCA so far. This study aimed to analyse the environmental performance of partial grazing with indoor feeding of fresh herbage with two levels of concentrate supplementation (< 500 vs 800 - 1,500 kg cow^{-1} yr^{-1} as vs a full-grazing system (242 - 265 d) with seasonal calving.

Materials and methods

The systems were analysed on 12 PF in 2014 (four farms per system) as well as on the EF of the vocational education and training Centre for Nature and Nutrition in Hohenrain (2014-16). Data were collected from a farm network system comparison described by Reidy *et al.* (2017). Missing data – such as the detailed building and machinery data used at each PF – was extrapolated from model farms and scaled to fit the farm that was analysed. Environmental impacts were calculated per kg of energy corrected milk (ECM) ((0.038 × raw fat content (g kg^{-1} milk) + 0.024 × raw protein content (g kg^{-1} milk) + 0.816) /

3.14) × milk (kg)) at farm gate, as the goal of the analysis was to compare the environmental impacts of the milk produced in the different systems. The system boundary included the cattle husbandry, feeding and manure management, production of feedstuffs, energy carriers, fertilisers, buildings and equipment. Breeding and fattening of cattle were included and physical allocation based on the net energy needed for the production of 1 kg of ECM (3.1 MJ) and 1 kg of bodyweight (14.1 MJ) was used to allocate the environmental impacts to the outputs milk and live weight. Other agricultural or land enterprises, such as crop production or livestock other than cattle, were deducted from the total inputs. On the EF, the cattle was split into three groups for the duration of the experiment. The inputs and outputs of the three systems were recorded separately for the three groups (number of animals, animal weight, milk produced, concentrated feed use, mineral fertiliser use, etc.) or split between the three groups (differently done for different aspects, e.g. gasoline was split by the total harvested area for each system, diesel by estimates by the person in charge of the experiment at Hohenrain). The direct emissions were calculated with the SALCA farm tool, which was especially adapted for taking into account specific characteristics of grassland and grazing based milk production (Nemecek and Ledgard, 2016). For instance, it was considered that N excretion in urine and dung on pasture lead to different N emissions. The impact assessment was calculated in Simapro by applying the SALCA impact assessment method. Carbon sequestration was not accounted for in permanent grassland in the global warming potential impact category, due to lack of experimental evidence. Inventories were from the ecoinvent V3 database.

Results and discussion

Due to the small sample size, no statistical tests were carried out. In the following, we only discuss differences if the range of data in one system did not overlap with that in the compared system. We only speak about tendencies if the minimum value of one system overlapped with the maximum of another. The following differences were found between the three systems kg^{-1} of ECM produced (some shown in Figure 1): Higher concentrate inputs (C) result in higher P and K (not depicted) resource use, deforestation (not depicted, compared to A) and ecotoxicity. For the other impact categories, the single farm results show a large spread and overlap between the feeding systems, especially for the PF

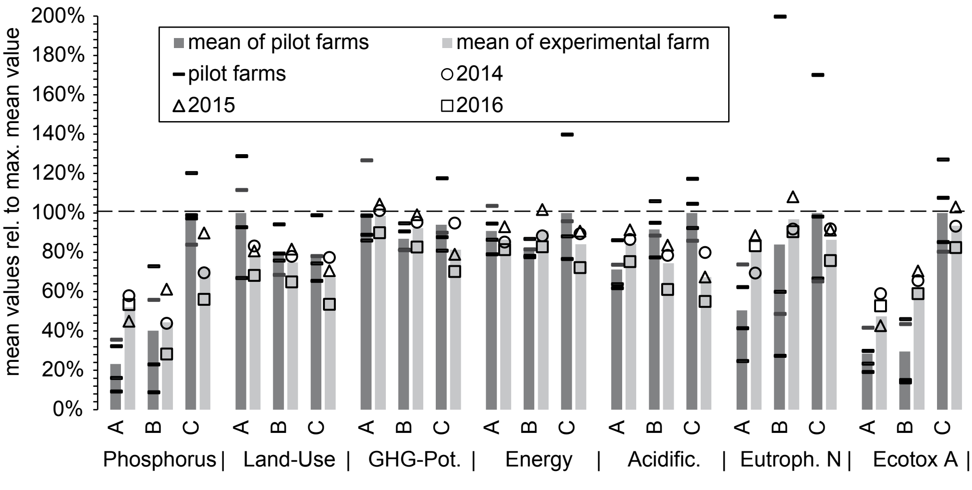

Figure 1. Selected LCA results per kg of ECM for three production systems, values relative to the maximum mean value of the respective impact category (A: full-grazing; fresh grass feeding in barn with B:, reduced concentrate; C: standard concentrate; PF: mean result of the four PF per system, EF: mean over the three years of the EF. Categories from left to right: mining of P resources [kg P], land-use [m^2a], global warming potential [kg CO_2-eq], non-renewable energy use [MJ], acidification potential [mol H + -eq.], aquatic N eutrophication [kg N], aquatic ecotoxicity [kg DB^{-1}, 4-eq.].

and for aquatic N eutrophication. However, system C tends to lead to lower global warming potential (only for EF) compared to the two others. Regarding the biodiversity indicator and the newly developed indicator on landscape-aesthetics, only relatively small differences were found between the three systems, with a tendency to better scores for the system with higher concentrate inputs (C) regarding landscape aesthetics, but a tendency to worse scores regarding biodiversity (results not shown).

Generally, the environmental impacts kg^{-1} ECM from the PF and from the EF are in agreement with each other, except for acidification. As expected, the results from the single PF are more widely spread than the results for the three years for each system from the EF. The purchase of animals – often ignored in studies of dairy production – is an important factor for almost all impact categories (12 to 37% of total impact over all the impact categories). Further important factors are – depending on the impact category husbandry, fertilisation and feed import (not depicted on figure).

Conclusion

The higher concentrate inputs resulted in higher P and K resource use, deforestation and ecotoxicity, whereas the systems with no or less concentrate tended to higher global warming potential per kg ECM (only for EF). However, other aspects in the management of each farm next to the feeding system influence the environmental impacts: the differences in environmental impacts per kg ECM were often larger between the single PF and the years than between the three systems. Four main factors influencing the environmental impacts were identified: (1) the composition of the feed ration, (2) the performance of the system (feed conversion ratio), (3) grazing and manure management, and (4) the purchase of animals.

Acknowledgements

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Dynamic LCA model for estimating environmental effects of Finnish beef production (FootprintBeef)

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Abstract

As ruminants cause a large proportion of global greenhouse gas (GHG) emissions and other environmental impacts of agriculture, studying the energy and nutrient flows in beef production systems is of high importance. A dynamic system model that integrates animal production, manure production and management, feed cultivation and their environmental impacts was developed to give a holistic view of the system and its hotspots in Finland. Production systems for both dairy and beef breeds were assessed and production intensity scenario studies were conducted for the different systems. With the most adequate production methods and animal material available, the reduction potential of current production is almost 25%. Still, many improvement options cause conflicting changes in different impact categories. For example, minimising the use of N fertilisers not only decreases nitrogen emissions, but also decreases dry matter yield, resulting in demand for a larger area for feed production. This leads to increasing P losses in surface runoff per kg of beef produced and compromises the environmental benefit of reducing N fertilisation. However, some improvement options cause conflicting changes in different impact categories. Thus, it is valuable that scenarios can be built combining multiple improvement options simultaneously.

Keywords: carbon dioxide equivalent, LCA, beef production, efficiency

Introduction

The agricultural livestock sector is responsible for a significant amount of GHG, eutrophying and acidifying emissions. According to the FAO (2006), 18% of total anthropogenic GHG emissions originate in the livestock sector (estimated using the life cycle assessment (LCA) approach). Cattle farming also causes water depletion and eutrophication. When considering Finnish production, the eutrophication impact is especially important to the state of the Baltic Sea and inland lakes. Cattle farming causes acidifying impacts from manure management and from different energy use, including field work and housing. The environmental impacts of cattle farming are very diverse and detailed observations are needed in order to estimate the sector's overall impact. Life cycle assessment is a well-adopted method for estimating the environmental impacts of the whole life cycle of selected products, but models integrating animal growth, feed production efficiency and land use demand are still quite rare. Usually, LCA consists of several impact categories, the best known and most common in agriculture being global warming potential and eutrophication impact. A standard method in LCA for food products is to use equations and factors provided by the IPCC. Comparing mitigation options for environmental impacts is difficult when they are based on rough or partial estimates. Characteristic of the system is its complexity: decreasing the environmental impact of one part of the system can lead to an increase in the impact of another part. Mitigation strategies must consider decreasing the negative environmental impacts of the whole system. Therefore, an holistic approach is essential to avoid unwanted trade-offs. So far, no tools have been available for evaluating the effect of management changes on the whole system. In addition to this, two separate systems are used in Finnish beef production: dairy breeds and beef breeds, which increase the complexity of the comparisons. These production systems differ in terms of breed, feed composition, animal age and weight at slaughter, type of housing and manure management systems.

The objective of this study was to develop a realistic and dynamic model to estimate the environmental impacts of cattle farming in Finland in the current situation, avoiding suboptimization. The aim of the study was to analyse potential impact on global warming, eutrophication of water systems and acidification from different Finnish beef production systems and to estimate the mitigation potential of different production strategies. The effects on biodiversity are excluded from this version of the model.

Materials and methods

The starting point for the model is one bovine animal (including only emissions from growing animals, proportion of suckler cows excluded), and from the energy requirement of the defined slaughter age and weight of one animal, the model calculates the minimum area requirement of feed production on a given diet for each scenario. The functional unit was defined as one kilogram of carcass weight of different cattle at the farm gate. The studied systems include the production and transport of farm inputs.

Three different production intensity scenarios were compared: the present system (PS, 60% grass, 40% concentrates for bulls; and 70% grass, 30% concentrates for heifers, based on statistical farm data averages provided by ProAgria and expert evaluations), a high-grass (HG) diet (80% grass, 20% concentrates for all animals), and a high-concentrate (HC) diet (40% grass, 60% concentrates for all animals). The model calculates the required land use for cultivation of the chosen feeds (grass, barley and oats) based on the energy requirement of the animal, the diet composition and the given yields of feeds. The model outcome is the smallest possible area to produce the desired amount of feed required for a chosen diet, i.e. the maximum stocking rate (LU ha^{-1} $year^{-1}$). Losses along the production process are not taken into account. The grass dry matter (DM) production submodule is based on a quadratic N response equation estimated from a large combined set of Finnish fertilisation experiments. The feed nutrients not used for animal growth end up in faeces and urine. To simplify the dynamic model created, it is assumed that all manure produced by a single animal is spread on the crops used to feed the same animal. The structure of the model is auto-regulative, allowing only biologically acceptable input values in scenarios.

Farm gate nitrogen and phosphorus balances serve as indicator values for nutrient-related environmental impacts of the production systems. The balances include nutrients in purchased fertilisers, feeds and minerals, and nutrient removal in animals sold. Global warming potential (GWP) describes the total climate impact of different greenhouse gasses, expressed in carbon dioxide equivalent. Aquatic eutrophication is estimated with calculated nutrient surpluses and mathematical models that estimate the amount of nutrient reaching waterbodies and available to cause eutrophication. More information of the model is given in Katajajuuri *et al*. (2015).

Results and discussion

The GWP of dairy breed bulls and heifers and beef breed bulls and heifers (without allocated emissions from dairy and suckler cows) for all the scenarios are presented in Figure 1. The differences between the animal groups calculated per kilogram of carcass weight are mainly caused by DM intake per kilogram of carcass weight and the length of fattening period, depending on the energy content of the diet. The reason for lower GHG emissions for beef breeds compared to dairy breeds is their better ability to convert feed energy to carcass weight. The most efficient scenario seems to be an HC diet. In an HC diet, the GWP of beef breed heifers is almost 13% lower than for dairy breed bulls on a PS diet. Even though this does not fully compensate for the emissions from suckler cows, it reflects the possibilities of feeding and more efficient animal material to mitigate GHG emissions. With the most adequate production methods and animal material available, the reduction potential of current production is almost 25%. This was achieved

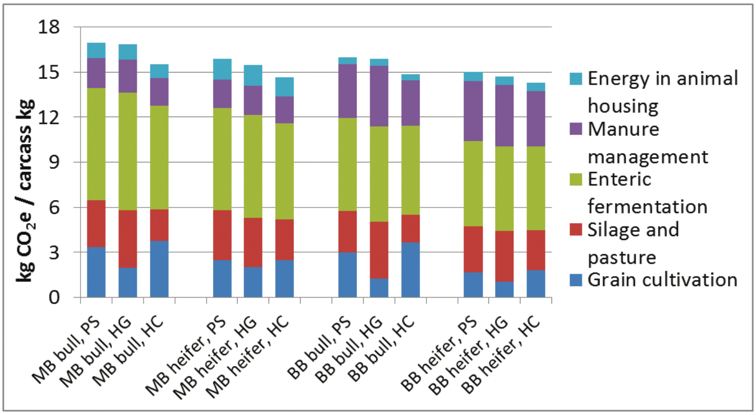

Figure 1. Changes in global warming potential when changing from the present system (PS) to high-grass (HG) and high-concentrate (HC) diets. (MB = milk breed; BB = beef breed, including emissions from growing animals only, proportion of suckler cows is excluded).

by shortening the growing period by 10% (but keeping same slaughter weight), achieving high silage and barley yields from the fields, aiming for high organic matter digestibility of silage, maintaining high production capacity of the fields and excluding organic soils from cultivation.

In some scenarios there may be a conflict between eutrophication potential (both N and P) and GHG emissions. For example, minimising the use of N fertilisers not only decreases nitrogen emissions, but also decreases dry matter yield, resulting in demand for a larger area for feed production. This leads to increasing P losses in surface runoff per kg of beef produced and compromises the environmental benefit of reducing N fertilisation.

Conclusion

A dynamic LCA model is needed for an holistic understanding of different emission pathways and also to improve the estimates of the most important factors for how to reduce different emissions while simultaneously avoiding unwanted trade-offs between emission sources.

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Net primary productivity and soil carbon balance of different forage production systems

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Abstract

Carbon sequestration has the potential to reduce greenhouse gas (GHG) emissions of forage production, yet data on intersystem comparability is scarce. Hence, in a field experiment in northern Germany, the aboveground (ANPP) and belowground (BNPP) net primary productivity of three forage production systems (a crop rotation (grass-clover, maize and winter wheat); continuous maize; and grassland) with and without fertilisation were quantified and a carbon budget was created. While the net primary production (NPP) was similar across all systems, the belowground fraction of the NPP (f_{BNPP}) was higher in grasslands with up to 35%, compared to 18 and 23% in continuous maize and the crop rotation. Aboveground biomass was comparable across years, yet in 2013/2014 the grassland and crop rotation benefitted from the mild winter, resulting in additional C input. Moreover, the crop rotation provided higher harvestable yields compared to grassland and similar figures compared to continuous maize, with an almost neutral carbon balance, whereas the continuous maize resulted in simulated decrements in soil carbon stocks of up to 18 t C ha^{-1} in the long-term (~100 years).

Keywords: forage production, carbon sequestration, grassland, continuous maize, roots

Introduction

Carbon sequestration is a promising tool for forage production to ameliorate the climate impact of ruminant agriculture. However, information on the carbon sequestration potential or even the belowground biomass of different production systems is scarce. Grasslands seem promising, due to their dense root system, while continuous maize is appealing for its high aboveground yields (Rees *et al.*, 2005). An advantage of the perennial and complex annual system is the continuous soil cover, which can prevent erosion and may result in additional carbon input in winter. However, a comparison on the impact of the production systems is difficult, due to a lack of comparable data. Hence, this work compared a perennial system (i.e. grassland, GR), a complex annual system (i.e. crop rotation, CR) and a simple annual system (i.e. continuous maize, MA) for the belowground biomass formed, as well as for the development in belowground carbon stocks that resulted from these production systems.

Materials and methods

The field experiment was established in the north of Kiel (N 54°27'55 E 9°57'55; 15 m a.s.l.) in autumn 2010, with measurements being conducted for ANPP and BNPP in two periods, namely between April 2012 - March 2013 (P_I) and April 2013 - March 2014 (P_{II}). The production systems were maintained after this time, however, to observe the long-term carbon impact by annual soil carbon measurements. Production systems included a perennial grassland (GR), (perennial ryegrass, timothy grass, smooth meadow grass and white clover), a maize monoculture (MA) and a crop rotation (CR). The crop rotation consisted of grass-clover (perennial ryegrass, red clover and white clover), followed by maize and winter wheat (with grass clover undersown). Each of the three production systems existed both as unfertilised treatments, as well as fertilised with 240 kg N ha^{-1} derived from cattle slurry, with the exception of the clover-grass in the crop rotation, which was not fertilised due to the large clover share. Belowground biomass growth was analysed using the ingrowth core method, with a sampling interval of four weeks throughout the growing season and one core for the winter period. Long-term changes in the soil carbon stocks were determined using the C-model of Petersen *et al.* (2005). Carbon input in annual systems was defined as the amount of roots and stubbles that were incorporated by ploughing, while excluding potential pre-harvest losses of senesced leaves. Since no ploughing was conducted in the grassland system in addition to carbon derived by roots, a shoot turnover (leaf litter and standing dead) of 28% was assumed (from Schuman *et al.,* 1999). Biomass production is reported as organic matter, due to the large differences in ash content particularly in the belowground biomass. Ash content was determined using NIRS and calibrated in a muffle furnace (24 h at 550 °C).

Results and discussion

The net primary production (NPP) was comparable among production systems with mean values of 13.3 t organic matter (OM) ha^{-1} in the grassland compared to 12.2 t OM ha^{-1} for continuous maize and 12.7 t OM ha^{-1} in the crop rotation. However, the harvestable aboveground biomass was lower (P < 0.01) in the grassland with 7.1 t OM ha^{-1} compared to 9.7 t OM ha^{-1} and 9.3 t OM ha^{-1} for continuous maize and the crop rotation, respectively. While these trends were similar for both experimental periods among production systems, a major difference within the periods became apparent in the root growth during winter. In the cold winter of 2012 / 2013, where monthly mean temperatures were still around 0 °C in March, root biomass formation was generally low with a mean of 0.2 t OM ha^{-1} for the grassland and below 0.1 t OM ha^{-1} for the crop rotation (Figure 1).

In the winter of 2013 / 2014, however, monthly average temperatures exceeded 5 °C in four out of the five months from November to March, with individual days in February and March reaching temperatures of 13 °C. Under these conditions, the grassland produced belowground biomass of 1.1 t OM ha^{-1}, and the crop rotation of 0.4 t OM ha^{-1}, thus increasing the benefits from a carbon storage perspective. The additional carbon input from complex annual systems and perennial grasslands will continue to increase in importance under climate change scenarios, which predict the growing season in northern Germany be extended by up to 80 days in case of a 5 °C temperature increment (Trnka *et al.*, 2011). Resulting from this additional carbon input, together with the reduced requirement for ploughing, with the complex annual system requiring ploughing only every second year due to the winter wheat cultivation with the undersown grass-clover, the effect on the soil carbon stocks increases substantially. As a result, in our model the soil

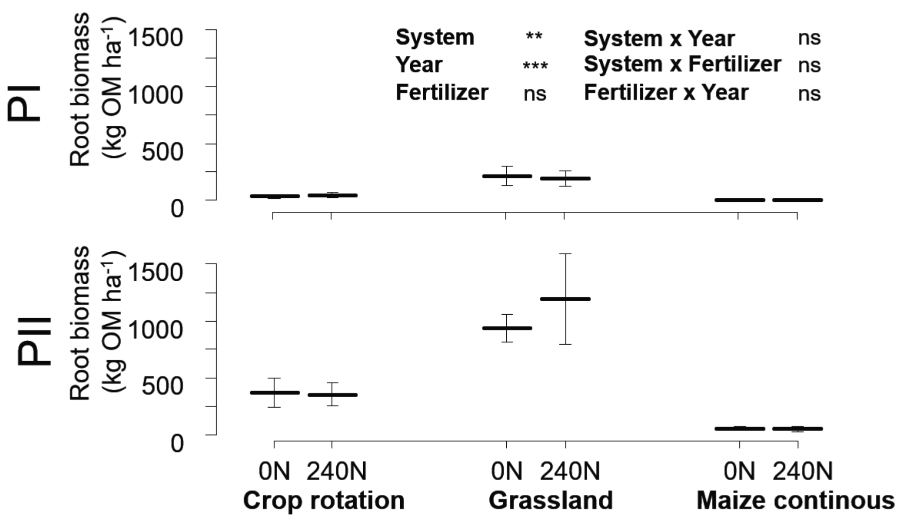

Figure 1. Mean (± S.E.) differences in formation of root biomass (ash-free organic matter) for the winter period in 2012 / 2013 (PI) and 2013 / 2014 (PII).

carbon content after 100 years was predicted to increase by 44 t C ha^{-1} under fertilised grassland cultivation and by 18 t C ha^{-1} for the unfertilised grassland, contrary to a depletion of soil carbon stocks by 7 t C ha^{-1} or 18 t C ha^{-1} for fertilised and unfertilised maize, respectively. The crop rotation, however, showed increments in soil carbon stocks by 3 t C ha^{-1}, and decreased by 7 t C ha^{-1} in the fertilised and unfertilised treatments, respectively. However, constant management practices yield and environmental conditions are assumed, leading to potential errors in the long-term prediction, even though soil carbon measurements showed a good fit to predicted soil carbon stocks (Figure 2). For fertilised grassland, high sequestration rates were observed during the first years of establishment, reaching nearly the equilibrium state after ~100 years underlining the high sequestration potential of permanent grassland with manure amendments.

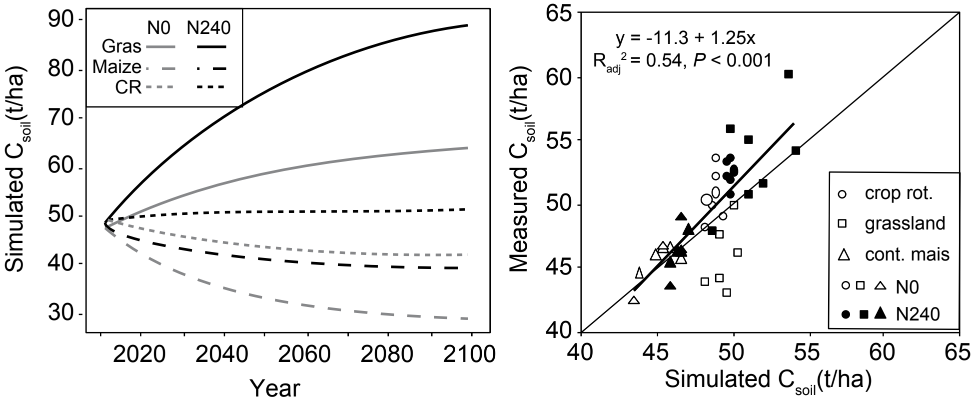

Figure 2. Modelled C stocks in soil for the Grassland (GR), continuous maize (MA) and crop rotation (CR), both without (0N) or with fertilisation using cattle slurry (N240). Model validation was performed using soil C measurements from 2011 - 2017.

Conclusion

Despite similar net primary productivity across the three production systems, harvestable aboveground biomass was lower in the grassland than in the crop rotation or continuous maize. This resulted in higher carbon inputs, however, thus making the grassland the best solution from a climate smart agriculture perspective. The crop rotation, however, managed to obtain comparable harvestable biomass to the continuous maize, while having an improved impact on the soil carbon content relative to the continuous maize. Additionally, the beneficial effect of the year round soil cover will continue to increase its importance under current climate change scenarios for northern Germany.

Acknowledgements

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Nitrogen and phosphorus fluxes of grassland-based dairy production systems on mixed farms in Switzerland

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Abstract

Farm gate balances for nitrogen (N) and phosphorus (P) were calculated for mixed crop-livestock farms in Switzerland for three types of dairy production systems: Partial grazing with indoor feeding of fresh grass with reduced (IF) and increased (IFplus) concentrate supplementation was compared with full-time grazing (FG). The aim was to identify the effects of the different systems on the N/P surplus per hectare and the N/P use efficiency (N/PUE). The mean values of the N surplus were 90.1 kg N ha^{-1} (FG), 91.8 kg N ha^{-1} (IF) and 133.6 kg N ha^{-1} (IFplus). The NUE was highest in IF (53.2%) and comparable for IFplus and FG (46.1 and 44.6%). Phosphorus surpluses were 2.5, 9.6 and 10.8 kg P ha^{-1} for FG, IF and IFplus, respectively. Some farms showed negative P balances. The PUE was 100.6, 76.5 and 70.0% for FG, IF and IFplus, respectively. Significant relationships were found between the N/P surplus and inputs of fertiliser, manure, concentrate and legume N fixation. NUE on IF and IFplus farms was significantly correlated with the percentage of arable land of the total farm land. An appropriate need-based feeding strategy and a low-loss use of fertiliser and manure might improve the N/P balances.

Keywords: nutrient use efficiency, nutrient surplus, system comparison, dairy farming

Introduction

Surpluses of nitrogen (N) and phosphorus (P) in farming systems are indicators of negative environmental impacts and inefficient use of agricultural resources. Farm gate balances provide an effective tool for the quantification of nutrient surpluses (Oenema *et al.,* 2003) and the identification of the improvement potential, especially if applied regularly. Within the scope of a system comparison of grassland-based dairy production systems, farm gate balances were calculated for 31 pilot farms. The main objective of this study was to analyse differences between the systems and to identify the most important factors influencing nutrient surplus and nutrient use efficiency.

Materials and methods

Farm gate balances were calculated for mixed crop-livestock farms practising one of the following three milk production systems: Partial grazing with indoor feeding of fresh grass with reduced (IF) and increased (IFplus) concentrate supplementation, and full-time grazing with reduced concentrate supplementation (FG) (Table 1). For the year 2014, all nutrient inputs and outputs of the farms were recorded. The inputs mainly consisted of mineral fertilisers, animal feeds, livestock and manure. Nutrient fluxes directly related to livestock production other than dairy cattle (pigs, poultry, horses, small ruminants, fattening cattle) were excluded. Manure applied to grassland from the other livestock sectors was accounted as input for after deducting 50% of the N losses from the total N content of the manure. Nitrogen input by biological N fixation of legumes was estimated based on the dry matter yields and legume contents of grassland according to Boller *et al.* (2003). Input from atmospheric nitrogen deposition was accounted for as 25 kg N ha^{-1} for farms in the valley zone and 20 kg N ha^{-1} for farms in the hill zone (BAFU, 2014). The nutrient outputs included milk, livestock, manure and products from arable farming (exported crops and other feedstuff). A clear demarcation of crop production was not possible. The nutrient surplus was

Table 1. Characteristics of the 31 analysed pilot dairy farms according to the three production systems, averages and range (in italics) for the year 2014.

Production system	Farmed area (ha)	Herd size (number of dairy cows)	Proportion of arable land (%)	Concentrate consumption (kg cow^{-1} $year^{-1}$)	Annual milk yield (kg ECM cow^{-1})
IF	26.6	35.7	28.1	425	7,125
n = 11	*11.0-60.2*	*16.2-70.3*	*0-70.4*	*111-718*	*6,367-8,349*
IFplus	29.7	44.3	29.6	991	8,225
n = 9	*14.3-59.6*	*28.5-76.0*	*5.8-52.2*	*623-1,534*	*6,893-9,619*
FG	31	36.8	13.9	115	6,444
n = 11	*19.3-42.5*	*21.0-60.5*	*0-43.4*	*0-347*	*5,024-8,535*

determined as the difference between inputs and outputs (Input-Output). From the ratio between the outputs and inputs, the nutrient efficiency could be calculated (Output/Input). Correlation coefficients were determined with R (R Core Team, 2013). After performing a Shapiro–Wilk test for normality, normally distributed parameters were computed using the Pearson method and non-normally distributed parameters using the Spearman method. Statistical significance was determined at $P < 0.05$.

Results and discussion

Due to the different farm structures, the variability between the farms was high (Table 2). The average N surplus was highest on IFplus farms at 133.6 kg N ha^{-1}. IF and FG farms were comparable to one another (91.8 and 90.1 kg N ha^{-1}). The NUE was highest for IF farms (53.2%) and on a comparable level for IFplus and FG farms (46.1%, 44.6%). The P surplus was highest for IFplus farms (10.8 kg P ha^{-1}, ± 7.8). IF farms showed a surplus of 9.6 (± 16.3) and FG farms showed a surplus of 2.5 kg P ha^{-1} (± 5.4). The average PUE was 100.6% (± 48.3), 76.5% (± 28.0) and 70.0% (± 18.6) for FG, IF and IFplus farms, respectively. Some farms showed a negative P balance due to low P inputs from feed and manure. The development of soil P reserves on these farms should be evaluated on a long-term basis. Significant relationships between the farm gate balance parameters could be found (Table 3). On IFplus farms, the

Table 2. N fluxes of the three dairy production systems in kg N ha^{-1} farmland and percentages of total inputs and outputs.

	IF		IFplus		FG	
N inputs	Ø ± SD kg N ha^{-1}	%	Ø ± SD kg N ha^{-1}	%	Ø ± SD kg N ha^{-1}	%
Dairy livestock	6.1 ± 4.4	3.3	9.7 ± 6.6	3.9	6.3 ± 3.1	4.0
Mineral fertiliser	22.9 ± 21.8	12.3	43.9 ± 21.0	17.7	39.1 ± 31.4	24.7
Manure	44.4 ± 35.5	23.8	38.5 ± 19.7	15.5	26.8 ± 18.2	16.9
Roughage/succulent feed	22.8 ± 21.2	12.2	28.1 ± 15.8	11.3	11.1 ± 7.5	7.0
Concentrates	24.3 ± 15.6	13.0	56.5 ± 12.5	22.8	4.9 ± 5.8	3.1
Biological N fixation	39.4 ± 13.8	21.1	47.0 ± 9.0	19.0	46.7 ± 7.1	29.5
Atmospheric N deposition	24.1 ± 2.0	12.9	24.4 ± 1.7	9.9	23.2 ± 2.5	14.7
N outputs						
Milk	45.0 ± 13.7	47.4	63.1 ± 13.3	55.1	33.0 ± 5.8	48.5
Dairy livestock	9.5 ± 5.3	10.0	14.4 ± 6.3	12.6	11.2 ± 3.3	16.4
Plant products	35.4 ± 31.0	37.2	28.9 ± 17.7	25.3	23.9 ± 24.5	35.1
Manure	5.1 ± 13.5	5.3	8.1 ± 14.7	7.1	0.0 ± 0.0	0
N surplus kg N ha^{-1}	91.8 ± 47.6		133.6 ± 25.3		90.1 ± 38.8	
N use efficiency (%)	53.2 ± 14.1		46.1 ± 6.8		44.6 ± 12.4	

Table 3. Correlation co-efficients between the parameters of the farm gate balances ($P < 0.05$).

	IF	IFplus	FG
N surplus vs input concentrates	$r = 0.58^{n.s.}$	$r = 0.88^{P=0.002}$	$r = 0.09^{n.s.}$
N surplus vs input mineral fertiliser	$r = 0.08^{n.s.}$	$r = -0.15^{n.s.}$	$r = 0.8^{P=0.002}$
NUE vs output milk	$r = -0.49^{n.s.}$	$r = 0.14^{n.s.}$	$r = -0.15^{n.s.}$
NUE vs percentage arable land	$r = 0.70^{P=0.016}$	$r = 0.86^{P=0.003}$	$r = 0.34^{n.s.}$
N surplus vs N fixation	$r = 0.38^{n.s.}$	$r = 0.55^{n.s.}$	$r = 0.71^{P=0.014}$
N surplus vs input manure	$r = 0.69^{P=0.019}$	$r = 0.56^{n.s.}$	$r = 0.46^{n.s.}$
P surplus vs input concentrates	$r = 0.74^{P=0.013}$	$r = 0.79^{P=0.012}$	$r = 0.67^{P=0.025}$
P surplus vs input manure	$r = 0.65^{P=0.037}$	$r = 0.97^{P<0.001}$	$r = 0.71^{P=0.015}$
PUE vs output milk	$r = -0.62^{P=0.042}$	$r = 0.18^{n.s.}$	$r = 0.12^{n.s.}$

N surplus and the input of concentrates were significantly correlated ($r = 0.88$, $P = 0.002$). The impact of arable farming (proportion of arable land to total farm land) on the N exports can be demonstrated with its correlation to the NUE, especially on IF and IFplus farms. On IF farms, a significant correlation was observed between N surplus and manure input. These inputs of manure mainly refer to the calculated data of demarcated other livestock. In comparison to IFplus and FG farms, IF farms imported the lowest amounts of mineral fertiliser. FG farms had lower inputs via purchased feed but higher inputs via mineral fertilisers and biological N fixation by legumes compared to IF farms. Combined with the lowest outputs of milk and products from arable farming, the FG farms showed the lowest NUE. With regard to P fluxes, all the systems demonstrated significant relationships between P surplus and the input of concentrates and manure. A significant negative correlation between the output of milk and PUE only existed for IF farms.

Conclusion

The results of the calculated farm gate balances showed considerable variability between farms. This demonstrates the need for individual farm analysis to develop adequate improvement strategies for each farm type as well as farm-specific recommendations. Concerning the different dairy production systems, IFplus farms showed the highest N and P surpluses. The highest NUE was found on IF farms while the highest PUE was on FG farms. To reduce surpluses and to improve the nutrient use efficiency, concentrate and fertiliser use should be optimised through an appropriate need-based feeding strategy and nutrient loss should be minimised in the use of fertiliser and manure. In most cases, better nutrient use efficiency will have benefits both for farm finances (reduced cost) and the environment (less emissions).

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Long-term trend in perennial ryegrass (*Lolium perenne* L.) delineator cultivar heading dates from 1984 to 2016

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Abstract

The annual variability in the temperate climates of Ireland, Northern Ireland and the UK is well recognised. The timing of heading (flowering) in crop species within a season is largely determined by responses to early season temperature and photoperiod. Numerous studies in Europe have shown earlier flowering across crop types (cereals, white clover and natural plant communities). During the last 33 years, the AFBI Plant Testing Station has evaluated forage perennial ryegrass cultivars as spaced plants under strict protocols to determine ear emergence (heading date). Examination of the mean date of ear emergence of perennial ryegrass delineator cultivars over the last 33 years provides evidence of phenology changes with earlier heading by 1.8 days per decade. The effects were evaluated using correlation and regression models for monthly mean temperature and heat sums (growing degree days). Differences in the distribution of plant heading date pre- and post-2000 were evident but not significant. The value of long term data sets on phenology and climate change are discussed.

Keywords: ryegrass, delineators, long-term, heading date, cultivar, climate change

Introduction

Crop phenology is inherently sensitive to variability in climate, with temperature being a major determinant of the rate of plant development, especially in the spring. Recent climate change studies covering a wide range of crops (cereals, white cover and natural plant communities) reveal earlier flowering by an average 2.5 days per decade (Menzel *et al*, 2006 a,b). Perennial ryegrass, *Lolium perenne* L., is the most important agricultural sown grassland species in the UK and Western Europe, where a predominantly grass-based agricultural industry plays a vital role in food sustainability and security. Plant breeders or their representatives must submit new cultivars for official statutory testing (UPOV, 2006) to ensure they are distinct, uniform and stable (DUS) before they can be released for sale. The timing of flowering is key in defining their commercial value with late and intermediate types of greater economic value than early maturing forage grass cultivars. The phenophase (mean date of ear emergence, MDEE = flowering/heading date) determines a cultivar's maturity class (early, intermediate or late) delineated currently by Lilora (16 May) and Barplus (1 June). This study examines the changes in MDEE of delineating cultivars over a 33 year period in response to the variability in NI temperatures. The value of long-term datasets for understanding changes in phenology in relation to climate are discussed.

Material and methods

Official statutory testing in the UK is undertaken in accordance with Articles 1, 7, 8 and 9 of the 1991 UPOV Convention (UPOV, 1991) for determining if a new cultivar is DUS. Ryegrass DUS is undertaken at the CPVO Entrusted AFBI Crossnacreevy, Plant Testing Station. New candidates are tested for two to four consecutive years as defined by species protocol (UPOV, 2006) against a reference collection of commercially available cultivars. The yearly MDEE for each cultivar is determined from 60 plants sown each year at 75 cm spacing with 10 plants per replicate. Annual MDEE from DUS trials for a 33 year period (1984 - 2016) were available for quantitative assessment of temperature responses. Individual plant heading from a subset of the data (1995 - 2016) were used to examine changes in the frequency distribution, timing of means and extremes for Lilora and Barplus for pre- 2000 and post-

2000. Daily meteorological data from 1984 - 2016 for Belfast were used to calculate the variability in monthly mean temperatures assessed by their standard deviations (SD), mean monthly temperatures and growing degree days (GDD > 5.5 °C) for the period March - May and GDD from 1 February and also from 1 March at the MDEE were analysed against their respective MDEE date using correlation and regression statistics (Payne *et al*, 2011).

Results and discussion

The results support the published results that variability is higher in earlier heading than later heading cultivars. This is partially explained by the variability in monthly mean temperatures for Belfast and the response of cultivars to increasing temperature. There was higher variability in monthly temperatures from January - April compared with May - September with an increase in October - December (Figure 1). These results are similar to UK and other European results (Menzel *et al.*, 2006a,b) for the between-year monthly standard deviations. This variability may cause temporal changes (shifts) in the distribution of plant heading date. This was investigated using data from 1995 - 2016.

The results reveal differences (Figure 2) in the distribution of the mean, median, upper & lower quartiles, first and last plant heading date (extremes) for the E-I and I-L delineators both pre- and post- 2000 periods; however, the changes were not significant ($P > 0.05$). This is most likely related to the shorter

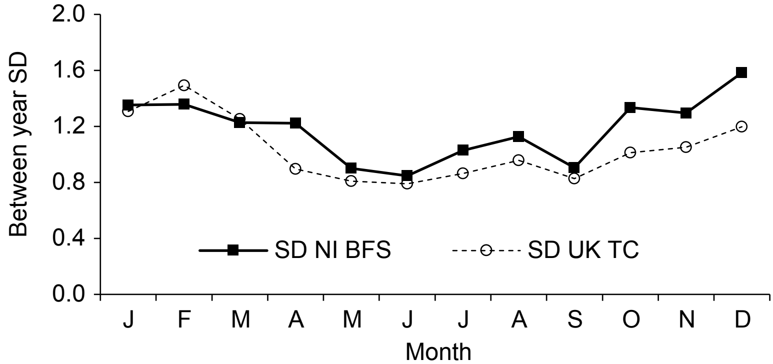

Figure 1. Between-year standard deviation (SD) variability in monthly mean temperature in Belfast (solid line, SD NI BFS) and UK (broken line, SD UK TC).

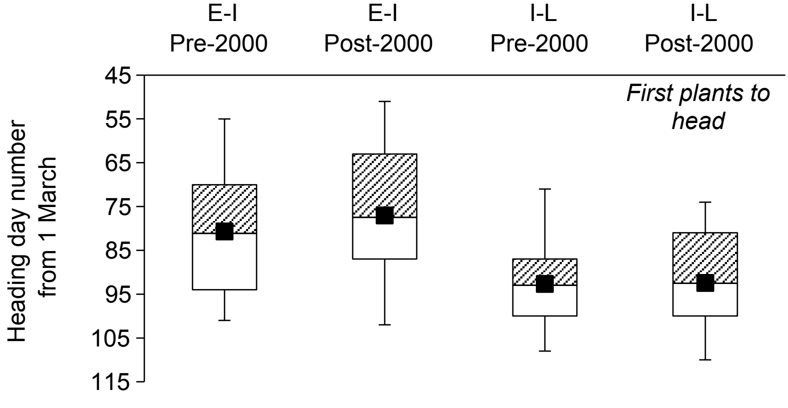

Figure 2. Description of E-I and I-L delineators for pre - and post- 2000 periods for mean (■), median (box plot), upper (hatched box plot) and lower (open box plot) quartiles and extremes (first and last plant - excluding outliers) in dates of ear emergence.

time periods examined, confirming results of Spark and Menzel (2002) as cited in Menzel (2006b). There was greater variability (Figure 2) found in the pre- 2000 data sets compared with the post- 2000 data. The E-I delineator has a more symmetric distribution (skewness 0.08) compared with I-L delineator (skewness -0.23). Individual data sets (60 plants per annum) were not available for the period 1984 - 1994 to confirm whether frequency distributions found are similar to those in Figure 2. The MDEE was significantly correlated with mean monthly temperatures two months preceding onset (March) for the E-I delineator (r = 0.118, $P < 0.05$ and one month (May) for the I-L delineator (r = 0.208, $P < 0.005$). Accumulated growing degree days also provided highly significant correlations ($P < 0.001$) for the month of May (GDD 1 February E-I r = -0.663 and I-L r = -0.793 and April for GDD 1 March (E-I r = -0.568 and I-L r = -0.769). Results for rainfall and sunshine hours for the same periods were less effective in predicting changes in MDEE. The response to raising temperature was assessed by the slope of the linear regression of the MDEE on the month before onset. Overall, MDEE exhibited responses to mean monthly temperature in both delineators, the E-I delineator had a slope of -0.584 (April) compared with the I-L delineator -2.293 (for May). The results support Menzel *et al.* (2006b), with highly significant coefficient of regressions two months prior to MDEE onset (-1.258), whereas the E-I delineator was highly significant for March temperature. Overall, results indicate a shift to earlier heading in both cultivars by an average 1.8 days per decade. ($P < 0.05$) This emphasises the value of long-term data sets derived from trials adhering to defined protocols throughout for examination of climate change responses.

Conclusion

The study shows delineator cultivar heading dates are 1.8 days earlier per decade with heading dates in early spring more variable than early summer. The study lends weight to the value of long-term data sets, such as the DUS trials in NI recorded under stable and strict protocols, in evaluating time-based changes. The importance of using other climate variables such as sunshine hours and rainfall merits further investigation, as would assessment of a larger number of cultivars or other species data to confirm these results.

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Response of plant functional traits to temperature along an alpine gradient of altitude

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Abstract

Alpine landscapes are characterised by extreme topography and climate conditions with grassland occurring at sites higher than 2,000 m a.s.l. For alpine grassland ecosystems, temperature is the most limiting environmental factor for growth. We hypothesised that the expression of morphological plant functional traits reveals variation in growth rates along temperature gradients. Therefore, a transplantation experiment was conducted to search for intra-specific differences of traits along a strong altitudinal gradient in Austria. Two widespread alpine grassland species (*Trisetum flavescens* L. and *Plantago lanceolata* L.) were cultivated in flower pots under greenhouse conditions and then positioned at four altitudes between 1,092 m to 1,929 m a.s.l. Leaf length (LL), plant height (PH), leaf area (LA), specific leaf area (SLA) and surface biomass were recorded during the observation period. Results clearly indicate a strong linear relationship of plant functional traits with rising altitude, mostly driven by temperature but probably also influenced by other environmental factors such as intensity of radiation.

Keywords: alpine grassland, leaf length, leaf area, specific leaf area, plant height

Introduction

Alpine grasslands are faced with extreme climatic conditions which impact growth of plants along strong gradients of altitude and temperature. Morphological and physiological properties, i.e. functional traits of plants trigger growth processes and are, therefore, very useful to explain their climate response (Rosbakh *et al*., 2015). In our study, we focused on numerical traits of two selected, widespread plant species, which can be found in many Alpine grassland ecosystems. By means of a transplantation experiment, along an altitude gradient we investigated (1) whether phenotypical trait plasticity occurs within a short time period and (2) whether functional traits are correlated to each other (Lenzen, 2016).

Material and methods

Golden oat grass (*Trisetum flavescens cv. Gunther*) and ribwort plantain (*Plantago lanceolata*) were sown and cultivated in flower pots under greenhouse conditions at AREC Raumberg-Gumpenstein (Austria) in April 2016. In June 2016, three pots (30 cm diameter, 25 cm depth) with golden oat grass and ribwort were positioned outdoor at four different altitudes (1,092 m, 1,396 m, 1,696 m and 1,929 m a.s.l.) in Filzmoos, province of Salzburg, Austria. All sites were south-facing and plants were enclosed in metal cages to avoid damage and losses by grazing. The sites were equipped with mobile weather stations to monitor soil and air temperature. Growing degree days (GDD) defined as the sum of differences between daily air temperatures and a base temperature of 5 °C were calculated for the observation period. Leaf length and plant height were measured six times and leaf area was recorded two times during the observation period. Yield and specific leaf area were measured at the end of the experiment, after removing the pots from the sites. Analyses of variance and Pearson correlation analyses were performed using SAS version 9.3.

Results and discussion

Growing degree-days during the observation period significantly differed between the four altitudes ranging from 272 to 130 °C d from the lowest to the highest site, indicating large differences in growth conditions. SLA of golden oat grass continuously increased from 374 to 460 $cm^2 g^{-1}$ dry matter, whereas SLA of ribwort plantain was significantly lower (P < 0.001) and only slightly varied from 187 to 227 $cm^2 g^{-1}$ dry matter with rising altitude and decreasing temperature (Figure 1a). These findings are in contrast with other studies which show a compaction of the leaf tissue system of Alpine plants with increasing altitude (Woodward, 1979), but a few studies also confirm an exceptional increase of SLA (Wright *et al.*, 2004). The relatively short observation period probably did not allow any fundamental modification which in nature is occurring evolutionary throughout generations.

Aboveground biomass yield of ribwort was twice as much as that of golden oat grass (P < 0.05) with a clear decrease along rising altitude of approx. 50% between the lowest and highest site for ribwort plantain and of approx. 60% for golden oat grass (Figure 1b). With increasing altitude and unfavourable growing conditions, lower yields were probably caused by reduced metabolic activity and by an allocation of dry matter into the root system.

Average plant height and leaf length of golden oat grass decreased either significantly (PH) or slightly (LL) with rising altitude. At the first altitude level, a pronounced increase of plant height was observed during the observation period, whereas at the other sites only a moderate increase occurred. Leaf length of golden oat grass decreased both along the altitude gradient and within the growing period. In contrast, ribwort showed only minor variation in average plant height and leaf length along the altitude gradient and during the growing period.

Both plant height and leaf area were positively correlated to leaf length for golden oat grass along all altitudes whereas plant height and leaf area exhibited (non-significant) positive and negative mutual correlations, respectively. For ribwort, plant height and leaf length were strongly positively correlated along the full gradient of altitude (P < 0.001), whereas the relationship between plant height and leaf area as well as between leaf area and leaf length was weak (Table 1).

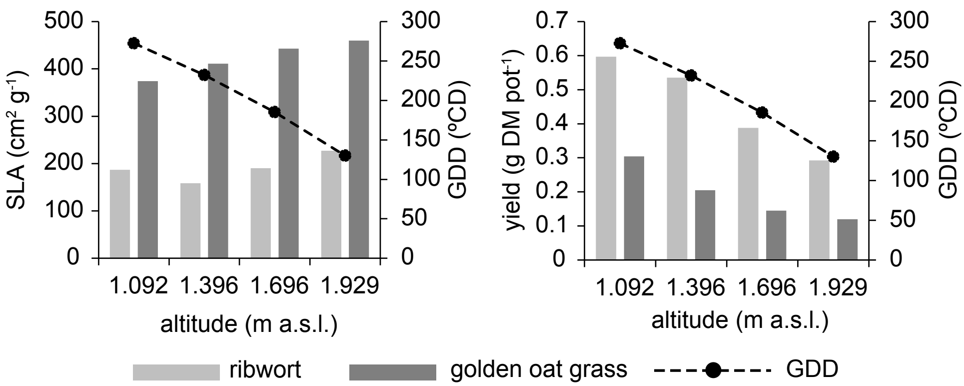

Figure 1. (a) Specific leaf area and (b) biomass yield of two species in relation to different altitudes and sum of temperature.

Table 1. Correlation matrix for functional traits of two Alpine grassland species along an altitude gradient (PH = Plant Height, LL = Leaf length, LA = leaf area).

Plant species	Altitude (m a.s.l.)	Functional traits	PH	LL
		PH	1	
	1,092	LL	0.58*	1
		LA	0.44	0.64*
Golden oat grass (*Trisetum flavescens* L.)		PH	1	
	1,396	LL	0.62*	1
		LA	-0.20	0.25
		PH	1	
	1,696	LL	0.55*	1
		LA	0.45	0.56
		PH	1	
	1,929	LL	0.32	1
		LA	-0.30	0.45
		PH	1	
	1,092	LL	0.99***	1
		LA	-0.31	-0.29
Ribwort (*Plantago lanceolata* L.)		PH	1	
	1,396	LL	0.99***	1
		LA	0.03	0.03
		PH	1	
	1,696	LL	0.99***	1
		LA	-0.35	-0.30
		PH	1	
	1,929	LL	0.98***	1
		LA	-0.30	-0.29

Conclusion

As hypothesised, functional traits of two selected Alpine plant species were significantly affected by a strong gradient of altitude. Genetically homogenous plants are able to adapt quickly to different environmental conditions indicating a high potential of phenotypic plasticity. Our findings are of increasing relevance in the context of climate change, which may alter metabolism, growth rates and phenology of individual species differently, influence grazing behaviour of ruminants and also pose challenges for farmers and agronomists with respect to adaptation of management.

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Semi-natural habitats on intensive grassland farms in Ireland

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Abstract

Intensification and specialisation of agriculture has resulted in a reduction in the quantity and quality of habitats associated with grassland systems. Remaining semi-natural farmland habitats (e.g. woodlands, hedgerows) provide important refuges for biodiversity, particularly within landscapes where a high degree of intensification has taken place. Semi-natural habitats provide biodiversity benefits by maintaining and enhancing species-richness which, in turn, facilitates the delivery of a range of ecosystem services such as pollination, flood protection, etc. that are integral to sustainable agricultural production. Additionally, they are the focus of several sustainability and environmental targets (e.g. Biodiversity Strategy 2020, Water Framework Directive, Climate Change Strategy). We investigated the percentage area of semi-natural habitats within 68 intensively managed grassland farms across Ireland. Preliminary results indicate that farms had 7.4% of their total farm area dedicated to semi-natural habitats. Hedgerows were the most abundant semi-natural habitat surveyed, and were, generally, in less than favourable condition. We discuss how management of existing semi-natural habitats can help maintain biodiversity within agricultural landscapes.

Keywords: intensive grassland, semi-natural habitat, sustainability, farmland

Introduction

Semi-natural farmland habitats such as hedgerows, woodlands, ponds, wetlands, etc. are associated with beneficial ecosystem services e.g. flood mitigation, carbon sequestration, pollinator habitat, water purification and decreased soil erosion. Farmland habitats are generally in decline and are the focus of several policies that aim to maintain and enhance them. Despite the importance of these semi-natural habitats, there is a distinct lack of data on the extent of habitats within European farms, especially in an Irish context. Without data pertaining to the quantity of these habitats present, relevant management and conservation measures cannot be established. Thus, it is important for the protection of these habitats that applicable data is obtained. A limited number of recent Irish studies (Sheridan *et al.*, 2011, 2017; Sullivan *et al.*, 2011) indicate that semi-natural habitats comprise between 13 and 15.2% of agricultural land. Previous studies focused predominantly on grassland farms incorporating a gradient of farming intensities. No single study has concentrated on the abundance, diversity or quality of semi-natural habitats on intensively managed Irish farms. We aimed to address this deficiency by investigating Irish grassland farms of higher agricultural intensity. This study quantified the percentage of semi-natural habitats on intensive grassland farms in Ireland and investigated the quality of some of these habitats.

Materials and methods

Eighty-one grassland farms, primarily in the south and east of Ireland, were surveyed between April 2013 and August 2017, of these, 68 have been analysed to date. Only farms with a stocking rate of 1.5 LU ha^{-1} or greater, or those in nitrates derogation, were chosen for the study. For each farm, a total farm walkover was undertaken as part of a habitat survey conducted in line with best practice guidelines (Smith *et al.*, 2011). The majority of farm habitat surveys were completed within one day with a small percentage running to two days duration. Habitats present were classified as those listed as Ecological Focus Areas for the purpose of Greening to maintain continuity with other sections of this research which focuses on tillage farms. All other habitats were classified according to Fossitt (2000) with the exception of transitional grassland/scrub (see Sheridan *et al.*, 2011). Non-cropped habitats were divided into two different categories – marginally productive habitats and semi-natural habitats. The habitats surveyed that were classed as marginally productive included wet grassland, plantation woodlands (conifer, broadleaf and mixed), transitional grassland/scrub, dry humid/acid grassland, scattered trees and parkland and fallow land. All other habitats were classed as semi-natural habitat – hedgerows, drains, buffer strips, earth banks, field margins, semi-natural woodlands, swamp, field copses, ponds, isolated trees, stonewalls, heath, constructed wetlands, marsh, springs and exposed rock. Survey data was digitised using ArcGIS software (Version 10.2) and the World Imagery base maps. Habitat maps were created for participating farms and used to calculate the area and lengths of each semi-natural habitat present on each farm. Coupled with the habitat survey, a subset of hedgerows per farm were surveyed (using a methodology adapted from Foulkes *et al.* (2013)) to gain an understanding of their quality. This system recognises two different measurements of hedgerow quality – Hedgerow Significance and Hedgerow Condition. Hedgerow Significance ranks the significance of hedgerows on a scale of 0 - 4 across five categories: Historical Significance; Species Diversity Significance; Structure, Construction and Associated Features; Habitat Connectivity Significance and Landscape Significance. A score of four in any category, or a cumulative score of six or 16 across assorted categories, indicates a hedgerow of high significance and should be highest priority in terms of retention, management action, etc. Low significance can indicate issues such as low species diversity or no connectivity with other semi-natural habitats. Hedgerow condition is a qualitative assessment based on desirable and undesirable attributes. The higher the recorded score, the more favourable the condition. Unfavourable attributes include, for example, poor basal density, gappiness, etc. Recording of hedgerow structural, ecological, landscape and continuity factors, in addition to negative indicators were undertaken in the field while historical factors were obtained using a desktop survey. Botanical species diversity data were recorded from two, non-concurrent, randomly located 30 m strips within each hedge.

Results and discussion

A total of 4,423.1 ha was surveyed across the 68 farms sampled, with an average farm size of 65.04 ha (± 3.94 s.e.). The average percentage of semi-natural habitats per farm surveyed was 7.4%. When marginally productive habitats were included, this percentage increased to 12.5%. Hedgerows were the most common habitat encountered, occurring on 100% of farms surveyed. Drains, buffer strips and field copses were the next most commonly occurring habitats present on 91, 86 and 75% of farms, respectively. Under the hedgerow significance category, a total of 129 out of 290 (44.5%) hedgerows were deemed to be significant (Table 1). Of these, 42.6% did not have any low category. The remaining significant hedgerows had at least one low category. Under the hedgerow condition category, the highest score obtainable is 24 with no Unfavourable categories. The average condition score obtained was 12.05 (Table 2). 14.5% of hedgerows had no Unfavourable category. All other hedgerows had at least one Unfavourable category.

The percentage of semi-natural habitat (7.4%) was lower than what has previously been reported for Irish farms, suggesting that farms with more intensive management have a lower percentage of semi-natural habitats present compared to those that are more extensively managed. Nonetheless, this percentage is still higher than the current EU Ecological Focus Area target which is the equivalent of 5% of cropped area at present (for tillage farms).

Table 1. Hedgerow Significance results showing the number of hedgerows that were calculated to be highly significant (High sig.) with varying low categories. The total number of hedgerows surveyed was 290 with 129 of those being highly significant.

High sig. with no low category	High sig. with 1 low category	High sig. with 2 low categories	High sig. with 3 low categories	High sig. with 4 low categories
55	46	22	5	1

Table 2. Hedgerow Condition score showing the average condition score and the number of unfavourable categories (unfav. cat.) for each hedgerow.

Total	Avg. Score	No Unfav. cat.	1 Unfav. cat.	2 Unfav. cat.	3 Unfav. cat.	4 Unfav. cat.	5 Unfav. cat.	6 Unfav. cat.	7 Unfav. cat.
290	12.05	42	75	69	40	30	28	4	2

Hedgerows occurred on 100% of farms in this study and accounted for 40% of all semi-natural habitats surveyed. The results obtained for the Significance and Condition of hedgerows however, showed that the majority of these hedgerows are in less than favourable condition with a high percentage showing low Significance or Unfavourable Condition categories. Sullivan *et al.* (2013) reported similar findings regarding hedgerow condition.

It has been shown here that the percentage of semi-natural habitats on intensive farms in Ireland is encouraging and would meet current EU Greening targets should grasslands be included in further revisions of CAP legislation. The quality of the most commonly occurring habitat, however, is less than favourable and clearly highlights where current legislation is inadequate for the proper conservation of biodiversity and its associated benefits. National and international agricultural regulations generally focus on habitat quantity and rarely mention the quality of habitats present within a farming landscape. Appropriate attention needs to be given to semi-natural habitat quality within agricultural schemes and requirements in order to obtain the optimum benefits which can be provided by these habitats.

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Grassland yield and nitrogen uptake as influenced by urea or ammonium nitrate based fertilisers

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Abstract

Urea has lower nitrous oxide emissions compared to ammonium nitrate in Irish temperate grassland and is less expensive. However, nitrogen (N) loss as ammonia from urea raises yield performance and efficiency questions. This six site-year study compares grassland yield and N off-take from plots fertilised with urea, calcium ammonium nitrate (CAN) and urea + the urease inhibitor N-(n-butyl) thiophosphoric triamide (NBPT). Five annual N rates (100 to 500 kg ha^{-1}) were applied in five equal splits during the growing season. On average, urea produced 103.5% of CAN yield in spring and 98.4% of CAN yield in summer. There was no significant difference in annual yield between the three fertilisers. However, urea had lower apparent fertiliser N recovery (AFNR), for example, at 200 kg N ha^{-1} yr^{-1}, 71%, compared to CAN (74%) and urea + NBPT (75%). The difference was more pronounced as the N rate increased, raising the question of urea yield effects over the long-term. Although urea had the least cost per Mg DM^{-1} produced, its ammonia loss is problematic for countries with commitments to reduce this emission. Promisingly, NBPT treatment of urea allows the agronomic performance of urea to consistently equal CAN across N rates by addressing the ammonia loss limitations of urea.

Keywords: nitrogen, urea, calcium ammonium nitrate, urease inhibitor, grassland, pasture

Introduction

Fertiliser nitrogen (N) input is a cornerstone of intensive farming systems globally, including those prevalent in temperate grasslands. Fertiliser, including N, is a large direct cost on farms, for example, in Ireland fertiliser represents 20% of direct costs on average (Hanrahan *et al.*, 2013).

Globally, urea is the predominant form of mineral N fertiliser used; however, UK studies have reported lower grass yields with urea compare with nitrate based fertilisers (Devine and Holmes, 1963; Chaney and Paulson, 1988). In contrast, in Irish temperate grassland no significant annual yield difference between urea and CAN fertiliser or in early season grass growth was reported by some studies (Watson *et al.*, 1990). Nevertheless, in Ireland CAN accounts for 84% of the straight N market (Duffy *et al.*, 2014) in sharp contrast to New Zealand grasslands where urea makes up 80% of the fertiliser N used (Dawar *et al.*, 2012).

The European Union has set a target to reduce greenhouse gas emissions by 40% by 2030 (European Council, 2014) and urea based fertilisers have lower nitrous oxide (N_2O) emissions compared to nitrate based fertilisers in temperate grassland (Harty *et al.*, 2016). However, there may be yield, efficiency and ammonia emission trade-offs involved in substitution of AN for urea. These trade-offs are problematic because European Union countries have also committed to reduce ammonia emissions. Urease inhibitors such as N-(n-butyl) thiophosphoric triamide (NBPT) overcome the ammonia loss weakness of urea (Forrestal *et al.*, 2016). The current study tests the hypothesis that the agronomic performance of untreated urea differs from CAN and from NBPT treated urea across N rates.

Materials and methods

Experimental sites

Field plot experiments covering a range of geo-climatic environments were conducted at three locations during 2013 and 2014. The locations were Johnstown Castle, Co. Wexford, Moorepark, Co. Cork and Hillsborough, Co. Down. The dominant grass species was perennial ryegrass (*Lolium perenne* L.). The experimental design was a randomised block with five replicates. Each experimental unit (the plot) measured 2 × 10 m at JC and MP and 2 × 8 m at HB. There were two factors in the experiment (a) fertiliser type i.e. CAN, urea, urea + NBPT and (b) N rate with 5 levels applied in five equal split applications of 20, 40, 60, 80 and 100 kg N ha^{-1} yr^{-1} between March and September. A zero N control treatment was included at all site-years. All fertilisers were granular products. The source of the urease inhibitor NBPT was Agrotain® (Koch Fertiliser LLC, Wichita, KS, U.S.A.) which was coated onto urea granules at a rate of 660 mg kg^{-1} (w/w). Plots received a basal application of P, K, and S in line with soil test recommendations. The period between fertiliser application and grass harvest varied over the course of the growing season to reflect the changing N assimilation and grass growth rates. Grass dry matter (DM) was recorded and N content was determined using a LECO combustion analyser (St. Joseph, MI, USA).

Apparent fertiliser N recovery (AFNR) was calculated as:

$$\text{AFNR}\ (\%) = ((\text{N offtake}_{\text{treatment}} - \text{N offtake}_{\text{control}}) / \text{N rate})) \times 100$$

Statistical analysis

The effect of the fertiliser N treatments on the dependent variables of grass yield and N off-take was tested using the PROC GLIMMIX procedure of SAS (© 2002-2010, SAS Institute Inc., Cary, NC, USA). The factors in the model were site-year, fertiliser N type, fertiliser N rate and their interactions as fixed effects with block as a random effect. The least square mean output of SAS is presented with significant differences determined at $P \leq 0.05$ using the least significant difference mean separation test.

Results and discussion

No significant fertiliser type effect on annual grass yield was detected (P = 0.087). When applied throughout the year CAN, urea and urea stabilised with the urease inhibitor NBPT gave comparable annual grass yields (Figure 1a). On average, urea was a little better yielding than CAN in spring, producing 103.5% of the CAN yield. In contrast, summer applied urea was a little poorer yielding than CAN;

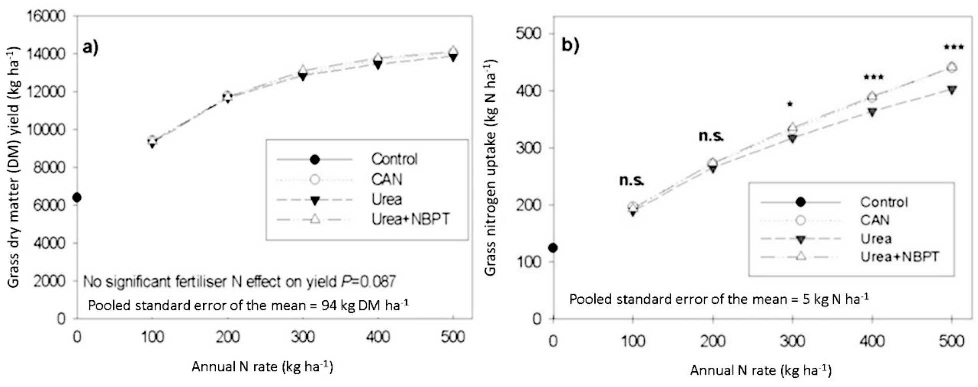

Figure 1. The effect of (a) fertiliser formulation on grass yield, and (b) nitrogen off-take efficiency based on summary of data from six site-years and 30 individual applications.

producing 98.9% of the CAN yield (Forrestal *et al*., 2017). As a consequence of similar yields between fertilisers, urea, the least expensive N fertiliser, produced grass at the lowest cost kg^{-1} DM in these single growing season trials at six site-years.

Despite similar yield the N off-take was affected by fertiliser N type with a significant fertiliser type × N rate interaction ($P \leq 0.01$) detected. There was significantly lower N up-take from urea compared with CAN and urea + NBPT; the difference between urea and the other fertilisers increasing as N rate increased. The practical implication being that urea is less efficient when applied at higher rates e.g. for silage vs lower rates e.g. in a grazing rotation. Harty *et al*. (2017) reported apparent fertiliser N recovery at 200 kg N ha^{-1} of 71% for urea, 74% for CAN and 75% for urea + NBPT in these trials. The lower N off-take from urea is associated with ammonia emissions from urea (Forrestal *et al.,* 2017) and lower N recovery raises the question of yield effects of using urea in the long-term. Long-term N fertiliser trials are in place at Teagasc Johnstown Castle to address this issue.

Conclusion

Nitrogen recovery and fertiliser efficiency is lower for urea compared to CAN and urea + NBPT, particularly at higher application rates. However, no difference in annual yield was detected in these single season trials with the result that urea had the lowest cost of grass production. Lower fertiliser efficiency and ammonia emissions from urea may make urea less desirable than other options from long-term yield stability and from national ammonia emission reduction commitment perspectives. Long-term fertiliser N trials are underway at Teagasc Johnstown Castle to investigate long-term yield stability effects of fertiliser type.

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Effect of nitrogen and phosphorus fertilisation and their interaction on nitrogen-phosphorus ratio of grass

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Abstract

In many EU countries fertilisation of grassland with nitrogen (N) and phosphorus (P) is limited by legislation. In earlier research in grassland experiments usually one nutrient was varied and a non-limiting amount of the other was applied. The interaction of the effects of N and P has been less addressed. Additionally, grass is sometimes presumed to have a constant N:P ratio. In the Netherlands, in the period 1994 - 2003, four separate field experiments were undertaken on four soil types. In these field experiments permanent grassland was fertilised with different N and P levels over a period of five and six years. Phosphorus fertilisation level had a negative effect and N fertilisation level had a positive effect on N:P ratio. At higher N levels, the influence of P fertilisation was stronger. Over time the (negative) influence of P fertilisation level also became stronger. The influence of N did not change systematically over time. Both N and P fertilisation levels should be taken into account to estimate N:P ratio.

Keywords: N:P ratio, N × P interaction, N fertilisation, P fertilisation

Introduction

In many countries within Europe, grassland yield is limited by both nitrogen (N) and phosphorus (P) fertilisation, due to legislation. In the past in grassland research most relationships between fertilisation and grassland yield and contents were observed by varying one nutrient and applying a non-limiting amount of the other nutrient. The interaction of the effects of N and P fertilisation has, however, been less addressed. Additionally, grass is sometimes presumed to have a constant N:P ratio. However, N content is in most cases not affected by P fertilisation but positively affected by increasing N fertilisation. Phosphorus content is affected by both N and P fertilisation (Schils and Snijders, 2004). The change of N:P ratio of grass by fertilisation is, therefore, hard to predict. In the Netherlands, in the period 1994 - 2003, four separate field experiments were undertaken. The objective of these experiments was to quantify the interaction of the effects of N and P fertilisation on DM yield and N and P content of grass. In these field experiments, permanent grassland was fertilised with different N and P levels over a period of five and six years. The objective of this paper is to examine the effect of N and P fertilisation and their interaction on the N:P ratio of grass.

Materials and methods

Four field experiments were conducted on permanent grassland sites in the Netherlands including sandy soil, marine clay, alluvial clay and peat soil. The soil P status, measured as P extracted with ammonium lactate, P-AL-value, was lower than the majority of grasslands in the Netherlands (Reijneveld *et al.*, 2010). The swards were dominated by *Lolium perenne* L. (LP). The experiments had multifactorial designs with four P fertilisation rates: 0, 22, 44 and 88 kg P ha^{-1} on sandy soil, alluvial clay and peat, and 0, 35, 70 and 105 kg P ha^{-1} on marine clay; and four or five N fertilisation rates: 0, 150, 300 and 450 kg N ha^{-1} on sandy soil and alluvial clay, and 0, 200 and 400 kg N ha^{-1} on marine clay, and 0, 150 and 300 kg N ha^{-1} on peat. The experiments had three replicates (all), and were measured during six (sand, peat) and five (marine and alluvial clay) experimental years. The treatments were randomly assigned to a plot within a replication. The plot areas were 3 × 10 m^2. Fertilisation levels were applied with the mineral fertiliser triple super phosphate and calcium ammonium nitrate. The experiments were mown in four to six cuts per year.

Yields of P and N were calculated for every cut as P and N content (g kg^{-1}) × DM yield (t DM ha^{-1}). Annual P and N yield were calculated by adding up all cuts on plot level. Weighted annual N:P ratio was calculated by annual N yield/P yield. The N:P ratio was statistically analysed in a linear regression model with a fixed and a random component. The fixed part comprised factors that could be controlled and quantified as explanatory variables, being soil type, N and P fertilisation, number of years and interactions. The random part comprised factors that could not be controlled or quantified being year (as factor) × site + site × plot + site × block. By including the random part the residual variance, against which the effects of treatments are tested, is reduced. The starting years were assigned a value of one for number of years. The parameters were estimated with the Restricted Maximum Likelihood (ReML) method (Harville 1977), using Genstat (18th edition). In the first step of the statistical analyses, the significance of factors and interactions was tested with an approximate F-test ($P \leq 0.05$). In the second step, a final model was developed by removing all non-significant main effects and interactions, so the model comprised only significant effects and interactions. This prediction model was applied by using the model-equations and filling in the parameter estimations and the terms to quantify the effects of the significant treatments and interactions.

Results and discussion

Phosphorus fertilisation level had, as could be expected, a negative effect on the N:P ratio (Figure 1). Nitrogen fertilisation level had a positive effect on both P yield and N yield but the effect on P yield was relatively and absolutely smaller than on N yield. As a result, N:P ratio increased with increasing N levels. At increasing N levels, the influence of P fertilisation was stronger. Over time the (negative) influence of P fertilisation level also became stronger. The influence of N decreased over time on alluvial clay, increased on peat and did not change on sand and marine clay. The change of the N effect over time was not systematic. The final model for annual N:P ratio was:

$$
\begin{aligned}
Y = \text{constant}_{\text{site}} &+ \beta 2_{\text{site}} \times \text{N fertilisation} \\
&+ \beta 4_{\text{site}} \times \text{N fertilisation}^2 \\
&+ \beta 6_{\text{site}} \times \text{number of years} \times \text{P fertilisation} \\
&+ \beta 7_{\text{site}} \times \text{number of years} \times \text{N fertilisation} \\
&+ \beta 8_{\text{site}} \times \text{P fertilisation} \times \text{N fertilisation} \\
&+ \beta 9_{\text{site}} \times \text{number of years} \times \text{P fertilisation}^2 \\
&+ \mu_{\text{site.year+plot.site+site.block}} + \varepsilon_{\text{plot.site.year}}
\end{aligned} \tag{1}
$$

The estimations of the β's are given in Table 1.

The interaction of the effect of P fertilisation level and number of years could be explained by the build-up of P in the soil at higher P levels by a positive soil surface balance, resulting in an increasing P-AL-value (data not shown). The increased soil stock contributed to a higher P uptake by the grass in following years. When there was a P deficit, P-AL-value of the soil decreased and P uptake by the grass decreased in the following years. The interaction of the effect of N fertilisation and number of years was not systematic over the sites. The effect of N was variable over years (data not shown). It is believed that significance of this interaction could be explained by the coincidental sequence of years with higher and lower N responses.

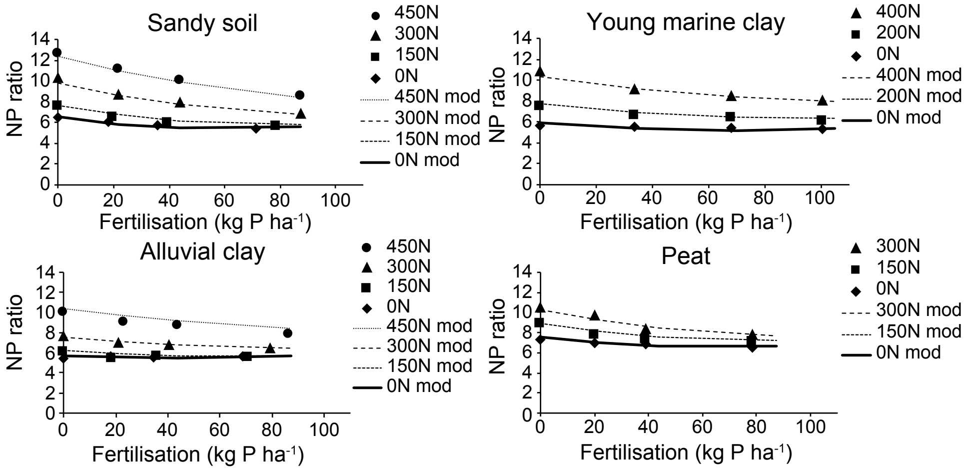

Figure 1. N:P ratio on four sites at different levels of N and P fertilisation, mean over experimental years; observations (markers) and model estimations (lines) with ReML.

Table 1. Results of statistical analyses; ReML estimates of factors affecting N:P ratio; means.

Parameter	Sand	Marine clay	Alluvial clay	Peat
Constant	5.9	6.5	5.7	7.5
β2 (Nfert)	0.0078	0.0065	0.0065	0.0066
β4 ($Nfert^2$)	0.000010	0.000015	0.000019	ns
β6 (Pfert × #yrs)	-0.00905	-0.01228	-0.00427	-0.01013
β7 (Nfert × #yrs)	ns	ns	-0.001696	0.0009629
β8 (Nfert × Pfert)	-0.00000446	-0.0000780	-0.0000496	-0.0000711
β9 ($Pfert^2$ × #yrs)	0.0000659	0.0000980	0.0000486	0.0000800

ns: not significant; random model: year (as factor) × site + site × plot + site × block; Nfert: N fertilisation; Pfert: P fertilisation; #yrs: number of years.

Conclusion

The N:P ratio of grass is strongly dependent on both N and P fertilisation. The N fertilisation level has a positive and the P fertilisation level a negative effect on the N:P ratio. The effect of P increases at increasing N fertilisation level. The effect of P fertilisation is higher on sandy soil than on marine clay, alluvial clay and peat. An accurate estimation for N:P ratio can be useful to optimise N and P fertilisation that are limited by e.g. environmental policies.

Acknowledgements

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New nitrogen fertilisation experiments challenge the old yield responses of forage grasses in Finland

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Abstract

Nitrogen (N) is the most important nutrient in yield formation of grass. Finnish N fertilisation recommendations and restrictions are based on field experiments mainly conducted from 1960 - 1970 with cultivars and management practices common for that time. The objective of this study was to update the yield response function of N to be better suited for modern grassland farming. Field experiments were conducted at two study sites in 2015 - 2017 with two modern cultivars of *Phleum pratense* L. and one cultivar of *Festuca pratensis* Huds. Development of DM yield, nutritive value and N balance were studied with eight N fertilisation levels (0, 150, 200, 250, 300, 350, 400 and 450 kg N ha^{-1} $year^{-1}$). The cultivars were harvested three times per season at the optimal stage for silage. The results indicate that the DM yield response is significantly stronger and N is used more efficiently for DM production than in the old experiments without compromising the nutritive value, especially during the first two years. The average maximum DM yield was as much as 1.5 times higher than in the old research results. The results have significant implications for the production economy and perceptions of the environmental consequences of grassland production.

Keywords: grass, nitrogen, nutrient balances, silage, timothy, meadow fescue

Introduction

The production capacity of forage grasses is substantially underutilised in Finland. Use of nitrogen (N) fertilisers in forage production is regulated by the Nitrates Directive and agri-environment schemes to control environmental impacts caused by N (Valkama *et al.*, 2016). Both yield responses and environmental indicators are based on Finnish experiments that were conducted mostly in the 1960s and 1970s (Salo *et al.*, 2013). A meta-study of Finnish N fertilisation experiments carried out between 1960 and 2012 on mineral soils showed that the maximum DM yields (8.5 Mg DM ha^{-1}) were achieved using an N fertilisation rate of 325 kg N ha^{-1} y^{-1}. Much higher yields have since been measured in both on-farm studies and field experiments (Virkajärvi *et al.*, 2015). The aim of this study was to update the yield response function to better respond to the productivity of current grassland farming.

Materials and methods

The experiment was carried out at two study sites in central Finland (Maaninka, 63°09'N, 27°20'E, sandy loam with 2.7% organic matter) and northern Finland (Ruukki, 64°41' N, 25°9' E, loam with 5.4% organic matter). The field trials were established in June 2014 using two cultivars of timothy (*Phleum pratense* L. cv. 'Grindstad' and 'Nuutti'; 3,000 seeds m^{-2}) and one cultivar of meadow fescue (*Festuca pratensis* Huds. cv. 'Valtteri'; 1,250 seeds m^{-2}). Barley was used as a cover crop. The plots were arranged according to an incomplete split plot design with four replicates. The main plot was the cultivar and the sub-plot was the N fertilisation rate (0, 150, 200, 250, 300, 350, 400 and 450 kg N ha^{-1}). The plots were harvested three times per growing season at the optimal stage for silage (digestibility approximately 680 - 700 g kg^{-1} DM). The N fertilisation was divided as follows: 44% for the first cut, 36% for the second cut, and 20% for the third cut. The P and K fertilisation levels were increased along with increasing the N fertilisation rate to avoid them becoming a limiting factor for growth. Finnish P and K fertilisation recommendations were used to set the lowest limits for these nutrients. Dry matter yields (kg DM ha^{-1}) were measured, and digestibility values (D value; g kg^{-1} DM) and crude protein (CP) concentrations (g kg^{-1} DM) were determined by near infrared reflectance spectroscopy (Valio Ltd) for each harvest. Nitrate N concentrations of yield (t kg^{-1} DM) were determined from five N rates (Yara Ltd, Pocklington, UK). Weighted means of D-value, CP concentration and nitrate N concentration were calculated for annual DM yields. Statistical analyses were performed using ANOVA (Mixed procedure of SAS 9.4). The experiment sites were analysed separately.

Results and discussion

In this study, yield response to N fertilisation was significantly higher and N was used more efficiently for DM production than in the past experiments (Salo *et al.*, 2013) without compromising the nutritive value (Figure 1, Table 1). In the first two years at both experiment sites, the DM yields with the highest N rates reached up to 13 - 15 t DM ha^{-1}, depending on the cultivar. In the third year, the yield response decreased, especially in Maaninka, where the highest total DM yield was 9.8 t DM ha^{-1} y^{-1}(N rate: 350 kg ha^{-1} y^{-1}). Part of the decrease can be explained by a natural decrease in productivity caused by physiological aging of plants and decreased grass density. In addition, mean air temperatures during the growing season were exceptionally low throughout Finland in 2017. After the winter of 2016 / 2017 significant winter damage (> 10%) was observed, with N rates of 400 - 450 kg ha^{-1} for meadow fescue in Maaninka, and with N rates above 300 kg ha^{-1} for all cultivars in Ruukki. The third harvest produced a significant proportion of the annual yield in all years (on average 23%) and used N effectively, which can be seen in the negative or close-to-zero N balances in all fertilisation rates, especially in the first two years.

Nitrogen fertilisation increased the CP content of forage in all cuts. Compared to the previous studies, N is now used more efficiently for biomass production without increasing the CP content. Increasing N fertilisation decreased the D value, especially in the first cut, but also in the second and third cut of timothy. The decrease in D value with higher N fertilisation rates is most likely linked to a decrease in the leaf : stem ratio. Mean nitrate N concentrations in grass DM increased linearly with the N rate over 250 kg ha^{-1} y^{-1} and were alarmingly high at the highest N rate (Table 1), but this varied depending on the cultivar, the cut and the year. The highest nitrate N concentrations were measured in 2016 for cv. 'Valtteri' from the third harvest in Maaninka (4,045 t kg^{-1}) and the second harvest in Ruukki (3,756 mg k^{-1}) with an N fertilisation rate of 450 kg ha^{-1} y^{-1}. The most plausible reasons for the improvements in the yield response to N are progress made in plant breeding, longer growing seasons with shorter winters and

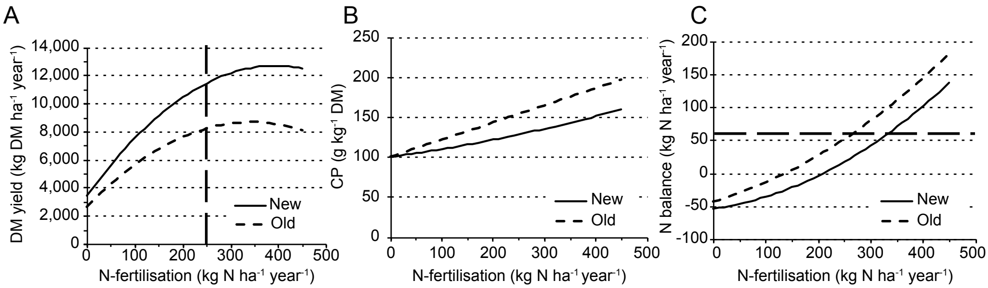

Figure 1. Effect of nitrogen (N) fertilisation on (a) DM yield; (b) crude protein (CP) concentration; and (c) N balance in grass in mineral soils based on past experiments (Salo *et al.*, 2013) and the present experiment. The response curve for the present experiment is based on two sites, three years and three cultivars. The current maximum limit for N fertilisation (250 kg N ha^{-1} y^{-1}; the vertical dashed line in a)) is based on the Nitrate Directive. The recommended limit for the N balance (+ 60 kg N ha^{-1} y^{-1}; the horizontal dashed line in (c)) is based on Salo *et al.* (2013).

Table 1. Effect of nitrogen (N) fertilisation on grass DM yield, digestibility (D value), crude protein (CP) concentration, N balance and nitrate N concentration. Values are averages of two sites (M = Maaninka, R = Ruukki), three years and three cultivars (C). Digestibility value, CP concentration and nitrate N concentration are calculated by DM yield-weighted means.

		DM yield t DM ha^{-1} $year^{-1}$		D-value g kg^{-1} DM		CP g kg^{-1} DM		N balance kg ha^{-1} $year^{-1}$		Nitrate N mg kg^{-1} DM	
Site		**M**	**R**	**M**	**R**	**M**	**R**	**M**	**R**	**M**	**R**
Nitrogenn	0	2.3	4.4	725	700	106	100	-42	-70	< 100	< 100
	150	8.2	10.3	715	688	115	109	0	-30	< 100	< 100
	200	9.8	11.6	709	681	127	116	5	-15		
	250	10.3	12.3	705	682	134	122	31	12	245	208
	300	11.7	12.9	698	682	148	132	29	29		
	350	11.6	13.2	698	679	154	137	70	61	859	808
	400	11.8	13.3	698	680	160	146	102	91		
	450	12.0	13.4	696	682	164	150	144	128	1,409	1,464
SEM		0.10	0.18	2.4	1.5	1.2	1.3	3.1	5.0	22.1	22.7
P-values[1]	Cultivar (0	***	***	***	***	***	ns	ns	***	***	***
	Nitrogen	***	***	***	***	***	***	***	***	***	***
	Year	***	***	***	***	***	***	***	***	***	***
	C × N	***	***	***	***	***	*	***	*	***	***
	C × Y	***	**	***	***	***	***	***	***	***	***
	N × Y	***	***	***	**	***	***	***	ns	***	***
	C × N × Y	***	**	*	ns	ns	ns	**	o	***	***

[1] ***$P < 0.001$, **$P < 0.01$, *$P < 0.05$, o $P < 0.10$, ns $P \geq 0.10$; SEM = standard error of mean.

improvements made in grassland management in general. The results will have a significant impact on estimation of economic and environmental effects of grassland N fertilisation.

Conclusion

The experiment showed a clear increase in DM production response to N fertilisation, as well as a concomitant decrease in both CP concentration and annual N balance compared to the earlier experiments. The biological maximum N fertilisation rate in mineral soils seems to be clearly higher than in previous studies. The results will have a significant impact on estimations of economic and environmental effects of grassland N fertilisation.

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Prediction of grassland values by phytosociological or agronomical approach

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Abstract

At the European scale, grassland classifications and policies are mainly based on a phytosociological approach. However, agronomists use other classifications, such as agronomical typologies, indicators, models, measurements of forage yield or quality. Grasslands in the Vosges Mountains (north-eastern France, 170 - 1,424 m a.s.l., 7,000 + km^2) have been studied following these two approaches in the last few years. Are these methods redundant or complementary? We compared a phytosociological classification made by botanists based on a sample of 550 grasslands and an agronomical classification from the study of 233 grasslands. This work did not show equivalences between the two approaches: the prediction of grasslands' ecological and agronomical values requires the association of both approaches. We, therefore, propose that current grassland classifications need both agronomical and phytosociological criteria in order to provide complete information on ecosystems and sustainable production.

Keywords: phytosociology, agronomy, typology, classification, methodology comparison

Introduction

Permanent grassland covers almost 60 million ha in the EU-27, which represents one third of total Utilized Agricultural Area (Eurostat, 2017). Since the 1970's, grasslands have been disappearing due to intensification and abandonment, with significant consequences for biodiversity. In order to protect biodiversity, the EU created a list of priority habitats based on phytosociology, which contain natural and semi-natural grasslands (European Commission, 2013). Phytosociology is the study of plant communities. It has been used since the early 20th century and provides a quick classification of the communities without accurate species abundance quantification (Ferrez *et al.*, 2016). Phytosociological classification mainly aims to describe communities and the conservation status of grasslands. Agronomical classifications allow the understanding of forage production and the impact of practices on the environment (Michaud *et al.*, 2013). Agronomical classifications are developed taking into account the abundance of botanical species. Estimating the ecological and economic values of grasslands is crucial for decision makers; no current classification allows the calculation of both values. The aim of this work is to compare the quality of assessment by both phytosociological and agronomical classifications.

Materials and methods

The study took place in the Vosges massif (north eastern France, 7,000+ km^2). Altitude varies from 170 to 1,424 m a.s.l., and geology differs significantly: from limestone and sandstone in the north to plutonic volcanic rock for the massif southern part. The climate is under oceanic and semi-continental influences and can be polar at the summits (Ferrez *et al.*, 2016). The phytosociological classification has been built by the Regional Botanical Conservatories, using 1,628 records from 1993 to 2015 on the entire Vosges massif (Ferrez *et al.*, 2016). The Botanical Conservatories identified 62 grassland types and selected 25 actually significantly present in commercial farms at the massif scale. We conducted our study on these 25 phytosociological types, based on 550 records. The agronomical classification was created from 2001 to 2013 by the Ballons des Vosges Regional Natural Park, the Vosges du Nord Regional Natural Park and the French National Institute for Agricultural Research (Collectif, 2006; Bayeur *et al.*, 2013). They interviewed 47 farmers about the management of grasslands and estimated yields from the number of bales and livestock stocking rate. They studied the botanical composition of 233 grasslands and identified 25 grassland agronomical types.

We evaluated the capacities of both classifications to predict ecological (total and oligotrophic species richness) and agronomical (yield) criteria. We used oligotrophic species richness as a proxy for species of high ecological value. We obtained the botanical specific richness and oligotrophic species richness of 783 grasslands from both phytosociological and agronomical classifications. In order to calculate oligotrophic species richness, we used Ellenberg indexes (Ellenberg *et al.*, 1992): we considered species with a nitrogen index of 1 to 3 as oligotrophic species. In order to study yields of phytosociological types, we attributed phytosociological types to the 233 agronomical relevés, based on the botanical composition. We analysed homogeneity of variance using Levene's test to study the dispersion of each criterion (total richness, oligotrophic species richness and yields) within the types of both agronomical and phytosociological classifications. In order to choose the best prediction model, we studied the impact of agronomical types, of phytosociological types, of the combination of both classifications, of the interaction of both classifications, and finally of a null model. We ran linear models for data with a normal distribution (total and oligotrophic species richness), and generalized linear model for non-normal distribution (yields). The best model is the one with the lowest second order Akaike Information Criterion (AICc), and we assume it needs to have a weight of at least 0.8. We controlled the quality of this best model by calculating its R^2 and comparing the AICc of the best and the null models. We performed statistical analyses using MuMIn and car packages from the R software.

Results and discussion

Results of the homogeneity of variance analyses and model selections can be found in Table 1. Total species richness is only significantly discriminated by phytosociological types. However, according to the model selection, no model is better than others to explain the total richness: the union of both classifications or the use of phytosociological classification alone are good predictors. Regarding these two analyses, the phytosociological classification seems to be a good approach to study total richness in grasslands.

Oligotrophic species distribution is significantly discriminated by both agronomical or phytosociological distribution and the best model to estimate oligotrophic species richness is achieved by combining the two classifications. This concludes that if each classification can be sufficient, the union of both best estimates oligotrophs richness.

Only agronomical types are significantly able to discriminate yields and the model based on agronomical classification is the best for predicting yields. We can conclude that phytosociology is powerless in yield prediction.

Table 1. *P*-values of homogeneity of variance analyses (*** = $P < 0.001$; * = $0.01 < P < 0.05$) and best selected model (A = Agronomical classification; A+P = combination of agronomical and phytosociological classifications).

Criteria	Homogeneity of variance analyses		Model selections
	Agronomical types	Phytosociological types	Best model (R^2)
Total richness	0.639	0.038*	-
Oligotrophic species richness	< 0.001***	< 0.001***	A + P ($R^2 = 0.63$)
Yields	< 0.001***	0.095	A ($R^2 = 0.50$)

Conclusion

Both agronomical and phytosociological classification are useful in grassland criteria prediction. However, each classification has advantages and the two can be combined to improve criteria predictions. To implement this study in European-scale grassland classifications, this analysis should be verified with other soils and climates and more criteria should be included such as forage quality. This European classification could lead to a better prediction of both agronomical and ecological grassland value. It is important to know the ecological value of a grassland in order to target the most threatened. However, grasslands need to be profitable to become durable, which is why we assume that European grasslands need an approach which combines both the phytosociological and agronomical approach.

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Intercomparison of nutritive value simulations in three process-based timothy grass models

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Abstract

Optimisation of the digestibility and concentration of energy and protein of forage biomass is crucial for good animal performance in ruminant production systems. The production of timothy (*Phleum pratense* L.) is well adapted to a wide range of cold-temperate climate, soil conditions and animal production systems. Several process-based models simulate the development of dry matter yield and nutritive value of timothy as a function of weather and soil conditions, and grassland management practices. We compared the ability of the models BASGRA, CATIMO and STICS to predict the concentration of crude protein (CP), neutral detergent fibre (NDF), and NDF digestibility (dNDF) in timothy in field experiments in Canada, Finland, Norway and Sweden with either cultivar-specific or generic (all cultivars calibrated together) model calibrations. The NDF concentration was underestimated by all three models. CATIMO overestimated and BASGRA underestimated the CP concentration and dNDF, whereas STICS overestimated dNDF.

Keywords: BASGRA, CATIMO, forage, grassland, STICS, digestibility

Introduction

Optimisation of nutritive value in grassland is crucial for the efficiency of ruminant animal production systems. Timothy is grown either in monoculture or in multi-species grass or grass-legume mixtures, harvested two-four times per year and conserved as silage under a wide range of climate and soil conditions with varying production potential. Process-based simulation models for grasslands express the physiological processes behind sward growth and development (Graux *et al.*, 2013). However, the responses to environmental factors vary between models. Model evaluations against field experiments under different climate, soil and management conditions could disclose information about the relative usefulness of the evaluated models to predict nutritive value under different environmental conditions. Our objective was to compare the process-based models BASGRA, CATIMO and STICS for predicting nutritive attributes of timothy grown in wide ranging conditions.

Materials and methods

All three models simulate the growth and development of timothy as a function of the weather, soil and cutting management and N-fertilization, with a daily time step. In CATIMO (Bonesmo and Bélanger, 2002a, b) and STICS (Jégo *et al.*, 2013), the crop nitrogen concentration that is required for optimal growth decreases with increasing shoot biomass, whereas in BASGRA (Höglind *et al.*, 2016), plant N requirements are determined by the sward leaf area index and the extinction coefficient. The NDF concentration is allowed to vary between stems, leaves and phenological stages in all three models. In CATIMO and STICS, it also varies with temperature. In BASGRA, dNDF decreases with phenological stage and in CATIMO and STICS also with temperature. Field experimental data on above-ground dry-matter, dry matter of stems and leaves, leaf area index, tiller density, and concentrations of water soluble carbohydrates, CP, NDF, dNDF and ash, and weather and soil data were obtained from Fredericton

(45°55’N; 66°32’W; 35 m asl), Lacombe (52°28’N; 113°44’W; 860 m asl) and Québec (46°47’N; 71°07’W; 75 m asl), Canada; Maaninka (63°09’N; 27°17’E; 90 m asl), Rovaniemi (66°35’N; 26°01’E; 106 m asl) and Ruukki (64°40’N; 25°06’E; 48 m asl), Finland; Særheim (58°46’N; 5°39’E; 90 m asl), Norway; and Umeå (63°45’N; 20°17’E; 12 m asl), Sweden. Not all data were available from all sites. The division into calibration and validation datasets took into account differences in data availability, climate and soil conditions, management practices and cultivars between the sites. Here we present the first results from the generic calibration (all cultivars calibrated together) for all locations and for cv. Grindstad for Maaninka, Ruukki and Særheim. For BASGRA and CATIMO, Bayesian calibration methods (Van Oijen *et al*., 2005) were applied. In STICS, NDF and dNDF related parameters were calibrated simultaneously by minimising the sum of squares of differences between their measured and simulated values. The model performances were evaluated with root mean squared error (RMSE):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}}$$

where n is the number of observations and P_i and O_i are the predicted and observed values for each data pair and RMSE divided by the mean of the observed values (normalised RMSE).

Results and discussion

For the generic calibration, all three models slightly underestimated the NDF in the calibration dataset. BASGRA also underestimated the CP and dNDF, whereas STICS overestimated dNDF and CATIMO overestimated the CP and dNDF in the calibration dataset (Table 1). BASGRA and STICS overestimated the NDF in the validation dataset. CATIMO had a poorer simulation accuracy for CP and dNDF than the other two models both for the calibration and validation datasets. For the calibration for cv. Grindstad, CATIMO performed better than in the generic calibration. Besides, the trends of CP, NDF and dNDF predictions were similar as for the generic calibration (Table 2). Simulation accuracy of the three models for CP, NDF and dNDF were of similar magnitude as their simulation accuracy for dry matter yield in a previous evaluation (Korhonen *et al*., unplublished data), which included data from many of the same experiments as in the present study.

Table 1. Observed mean and simulated mean, RMSE and NRMSE of CP, NDF and dNDF from the generic calibration.

	Mean of observation (g g^{-1} DM)	Mean of simulation (g g^{-1} DM)	RMSE (g g^{-1} DM)	Normalised RMSE (%)
Crude protein				
BASGRA	0.14	0.14	0.026	19
CATIMO		0.28	0.16	116
Neutral detergent fibres				
BASGRA	0.56	0.56	0.050	8.8
CATIMO		0.55	0.095	17
STICS		0.56	0.066	12
Digestibility of neutral detergent fibres				
BASGRA	0.78	0.75	0.072	9.3
CATIMO		0.51	0.29	38
STICS		0.79	0.050	6.4

Table 2. Observed mean, and simulated mean, RMSE and NRMSE of CP and NDF from the calibration of cv. Grindstad.

	Mean of observation (g g^{-1} DM)	Mean of simulation (g g^{-1} DM)	RMSE (g g^{-1} DM)	nRMSE (%)
Crude protein				
BASGRA	0.15	0.14	0.034	23
CATIMO		0.18	0.075	50
Neutral detergent fibres				
BASGRA	0.55	0.51	0.060	11
CATIMO		0.54	0.088	16
STICS		0.55	0.059	11

Conclusion and perspectives

This study showed that BASGRA and STICS predicted NDF and dNDF better than CATIMO. BASGRA also predicted CP better than CATIMO. The cultivar-specific calibration, which was performed for cv. Grindstad on three locations, gave lower RMSE than the generic calibration for seven cultivars on eight locations. The importance of climate, soil and management variability in the prediction of nutritive value could be further evaluated by comparing calibrations, which include multiple sites with different climate and soil conditions, with single site calibrations.

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Eco-efficient milk production in northern Germany inspired by the Irish rotational grazing system

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Abstract

The recent intensification in European dairy production has raised environmental and sustainability questions about the current housed systems. Pasture is considered to be the cheapest forage but its role in continental milk production is declining rapidly. The project focuses on an approach to fulfil relevant ecosystem services linked to dairy systems: high quantity and quality of agricultural commodities; low nutrient surpluses for clean water; low carbon footprint for mitigating climate change and seed mixtures contributing to agro-biodiversity. We are analysing the potential of pasture-based milk production based on 80 spring-calving Jerseys as an alternative to the traditional confinement system with HF-breeds. Records collected include: pre- and post- grazing forage yield and quality, nitrogen fluxes, GHG emissions, milk production and quality as a function of sward botanical composition. The first results demonstrate that a rotational grazing system based on spring calving can sustainably produce milk under German conditions. Annual dry matter yields of non-fertilised grass + clover swards were comparable to those realised in Ireland with a fertiliser application of 150 kg N ha^{-1}. On average, nitrate concentration in drainage to the groundwater remained below the EU-threshold value of 50 ppm.

Keywords: rotational grazing, grass, clover, eco-efficiency

Introduction

Recent intensification in European agricultural production is followed by serious environmental trade-offs questioning sustainability of current specialised production systems for both arable crops and animal products. Mixed crop-livestock farming is considered as a strategy to enhance sustainability (Ryschawy *et al.*, 2012). Under the maritime conditions of northern Germany, ruminant-based mixed farming systems are discussed as an alternative to specialised systems. With respect to ruminant nutrition, pasture is considered a cheap and environmentally friendly forage source (Dillon *et al.,* 2008; Rotz *et al.,* 2009). This is the background for the interdisciplinary project: 'Eco-efficient pasture-based milk production' that started in 2016 at Kiel University's research farm, Lindhof in northern Germany. The project focuses on an approach to fulfil all relevant ecosystem services linked to dairy systems: high quantity and quality of agricultural commodities; low nutrient surpluses for clean water; low carbon footprint for mitigating climate change and seed mixtures contributing to agro-biodiversity. We, thus, analyse the potential of pasture-based milk production on grass + clover leys to strengthen sustainability of an organic arable crop rotation.

Materials and methods

At the Lindhof research farm (N 54° 27' 55 E 9° 57' 55; mean air temperature 8.7 °C; mean annual precipitation 785 mm) a pasture-based dairy herd of 80 spring-calving Jersey cattle was introduced in 2016 to make use of the organic grass + clover leys grown in rotation with arable crops. Records collected are: forage yield and quality, nitrogen fluxes, GHG-emissions, milk production and quality as a function of sward botanical composition. The presented grass + clover growth rates were derived using the method of Corrall and Fenlon (1978) based on sampling of grass + clover leys in their first full year of production over four consecutive experimental years (2014 - 2017). No additional nitrogen was applied to the swards which for establishment were undersown in winter spelt in the preceding year as a seed mixture consisting of 20 kg ha^{-1} *Lolium perenne*, 2 kg ha^{-1} *Trifolium repens* and 6 kg ha^{-1} *Trifolium pratense*. Nitrate leaching to groundwater was determined by ceramic suction cups. Water was sampled weekly during the winter 2016 - 2017 and analysed for NO_3 concentrations. The volume of drainage water was calculated by a general climatic water balance model.

Results and discussion

Figure 1 shows dry matter (DM) yields and daily pasture growth rates (DPGR; kg DM ha^{-1}) for grass + clover at Lindhof (2014 - 2017) compared to DPGR measured at Solohead Research Farm in Ireland (52° 51' N; 08° 21' W) between 1999 and 2006, of grassland fertilised with varying amounts of nitrogen. The average DM yields of grass + clover without inorganic N fertiliser at Lindhof were similar to those of grass dominated swards at Solohead when fertilised with 150 kg N ha^{-1} yr^{-1}. These first results demonstrate the high yield potential of organically managed grass + clover swards at Lindhof. The dynamics of DPGR exhibit the typical pattern of seasonal growth in temperate regions but with the difference that pasture growth in spring starts one month later at Lindhof than under the milder conditions in late winter in Ireland, while higher maximum DPGR were measured in northern Germany in late May when the sward dominating clover found optimal growth conditions.

Figure 2 illustrates the 2017 production profile of grazed paddocks at Lindhof. In total 12.2 t ha^{-1} yr^{-1} DM were offered as pre-grazing mass to the dairy herd, while the total post-grazing mass accounted for 3.4 t ha^{-1} yr^{-1} DM, resulting in a forage use efficiency of 72%. For grass + clover in the 1st production year, grazing resulted in lower clover contents but higher leaching losses compared to harvesting for silage. In grazed swards, clover content declined with increasing sward age from 58% in the 1st year to 42% in the 2nd year.

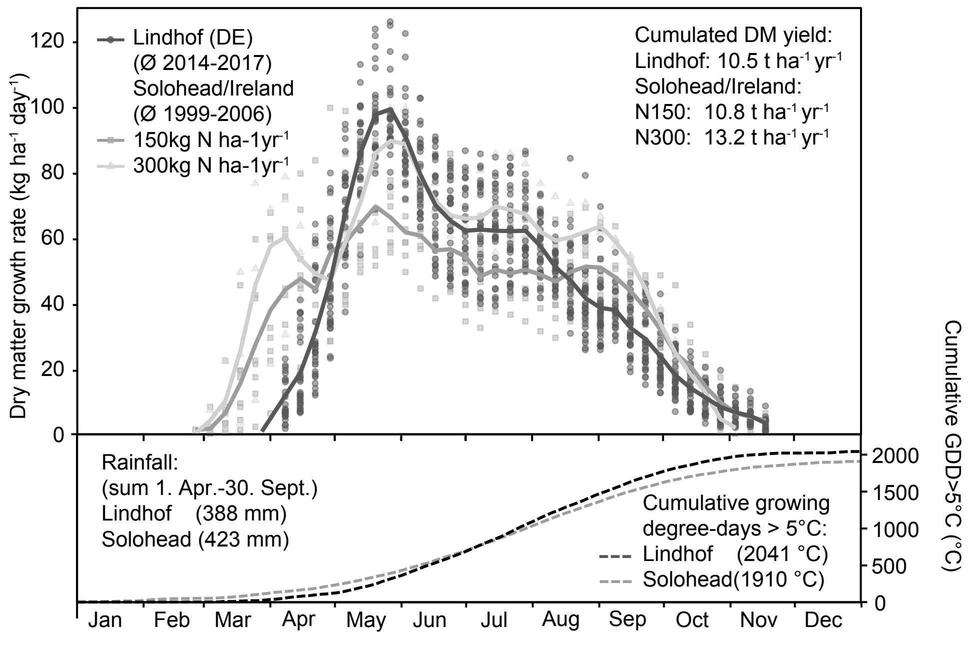

Figure 1. a) Daily growth rates (kg DM ha^{-1}) for grass + clover without inorganic N fertiliser at Lindhof (2014 - 2017) compared to daily growth rates measured at Solohead (1999 - 2006) of grassland fertilised with 150 kg N ha^{-1} yr^{-1} and 300 kg N ha^{-1} yr^{-1} respectively, b) cumulated growing degree-days > 5 °C at Lindhof (2014 - 2017) compared to Solohead (1999 - 2006).

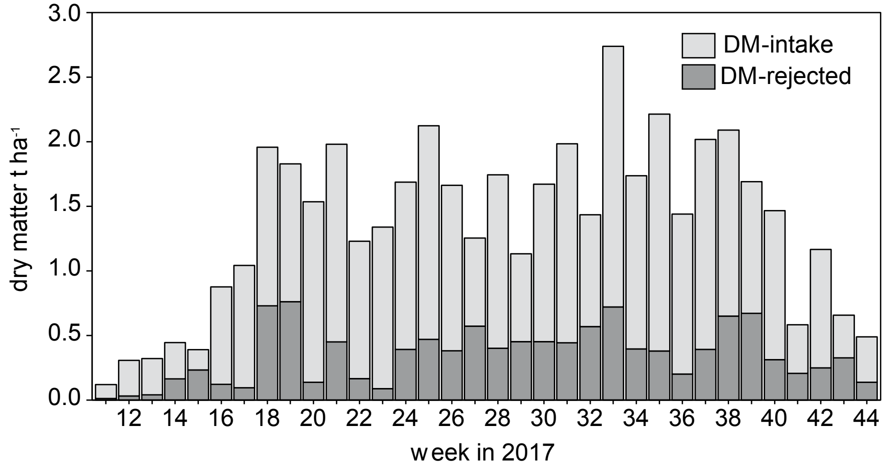

Figure 2. Average pre- and post- grazing mass of DM above a cutting height of 4 cm during the 2017 grazing season (13 March to 15 November) at Lindhof.

In 2017, each paddock out of 21 was cut at least once during the grazing season for silage making and grazed in at least eight rotations with one - two days grazing time each. In addition to grazed grass + clover, the dairy cows were fed with 2-3 kg cow^{-1} day^{-1} of concentrate, ending up with 620 kg cow^{-1} $lactation^{-1}$. Silage was only supplemented during the initial phase of lactation from February until April and from mid-October until the end of lactation, when cows were grazing for only half a day. In total, 1050 kg DM of high quality grass + clover silage were fed cow^{-1}. In total, 68% of milk production came from grazed grass, ending up in 10.6 tons of solids-corrected milk (equivalent to 994 kg of milk solids) ha^{-1} forage area and 431 kg of milk fat + protein (MS) per Jersey cow. For comparison, target values for Irish milk production are 1,200 kg ha^{-1} MS in a conventional system and approximately 825 kg MS ha^{-1} under an organic system. Grazed grass + clover in the 1st and 2nd year of production showed higher leaching losses than permanent pasture (data not shown). On average, nitrate concentration of drainage remained clearly below the EU-threshold value (50 ppm).

Conclusion

The first results demonstrate the potential of a rotational grazing system for sustainable milk production by dairy cows based on spring calving as an alternative production system under the conditions of northern Germany. Further research projects regarding economic assessments of the system and GHG emissions are in progress.

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Ley production potential as affected by climate change at high latitudes

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Abstract

Examples of climate change throughout the century were quantified using HadGEM2-ES-RCP45 scenarios (2070 - 2099) as compared with baseline data (1981 - 2010) for three sites, Rygge (59.4°N), Værnes (63.5°N) and Tromsø (69.7°N). The daily mean temperature for May through August was estimated to increase by 2.2 - 2.7 °C, while the length of the mean growing season (5 to 5 °C) increased some 28, 33 and 40 days, respectively, for the sites. Changes in total precipitation and its distribution through the year were relatively small. Potential evapotranspiration increased slightly. Forage DM yield was estimated from climatic, soil and management factors by the updated COUP-ENGNOR ley crop model; accounting for the benefit of long photoperiods, and calibrated against field trials with continuous growth curves obtained from weekly sampling of timothy ley yield during ten weeks at Ås (59.7°N) and Tromsø. The extended growth period allows an increase from three to occasionally four seasonal cuts in southern Norway and from two or one cut to three or two cuts when moving northwards. Drought periods, frequently occurring during midsummer in south eastern Norway will counteract the yield increase.

Keywords: grassland, climatic change, high latitudes, model

Introduction

The future global warming, estimated in most climate change scenarios, indicates an important increase in grassland production potential in Norway, not least in mountainous (Baadshaug and Haugen, 2009) and the northernmost regions. Our objective was to investigate effects of climate change by comparing sites at latitudes from South (Rygge 59.3°N), through central Norway (Værnes 63.5°N) into the Arctic region (Tromsø 69.7°N).

Materials and methods

The applied model was derived from the ENGNOR crop growth model (Baadshaug and Lantinga, 2002); for this case calibrated to first year pure timothy ley growth curves with ten weekly samplings during spring growth and to re-growth curves starting after an early and a late first harvest, respectively. In this revised version, light absorption was calculated for each hour during the light day and each of maximum six unit leaf layers down the canopy. Soil texture of a sandy loam, commonly found below the marine limit all over the country, was applied for all sites in order to 'isolate' the climatic effect. The soil moisture conditions were calculated on daily time steps for an upper 40 cm layer, divided in four equal sublayers. Soil water saturation was allowed to drain to field capacity (-10 kPa tension) during three days. Plant available water was considered as readily available in the tension range 0 to -100 kPa and gradually less available from -100 to -1,500 kPa. The actual daily soil surface evaporation and the plant evapotranspiration were estimated from potential evaporation (Penman, 1956) and the leaf area index (Ritchie, 1972). A HadGEM2-ES-RCP45 scenario (2070-2099) was compared with baseline data (1981 - 2010) for three sites, Rygge (59.4°N), Værnes (63.5°N), and Tromsø (69.7°N).

Results

The actual scenario indicates a mean yearly air temperature at the three sites to increase by 2.4 - 2.6 °C towards the end of the century, whilst the increase for the May - August season to be slightly different, 2.2 - 2.7 °C (Table 1). The growth season determined as the interval between passage of diurnal mean temperature of 5 °C in spring and autumn, increased by some 28, 33, and 40 days from the south to the north. The changes in seasonal precipitation and global radiation were rather small. The increase in potential evapotranspiration, Ep, was unexpectedly small, amounting to 20, 24, and 8 mm or 4.9, 6.4 and 2.6% seasonally, respectively, for the three sites (Table 1). The summarised drought stress (1 - Ea/Ep) decreased during the first growth (Table 2). Only during the third period at Rygge and Værnes, an appreciably increased drought stress occurred.

Total seasonal yields (Figure 1, Table 2) were estimated to increase strongly during the century by 15, 15 and 21%, respectively, for the sites. The main difference among sites was a yield reduction in the second cut at Rygge and Værnes, and a 57% increase of that harvest in Tromsø, which got no yield increase in the first harvest. The drought stress (Table 2) was relatively low during the first growth at all sites, especially by future climate conditions. During second growth, the stress was relatively high but stable at Rygge, lower but increasing at Værnes and Tromsø. During the (eventual) third growth, the drought stress will seemingly be more severe in the future.

Table 1. Mean temperature (TAM °C), rain and snowfall (PREC mm), global radiation (RAD MJ m^{-2} d^{-1}), potential evapotranspiration (EP mm d^{-1}) and sum (Eps mm) of May through August during baseline period and changes of future scenario at three sites in Norway.

Site	Period	Annual	During May through August				
		TAM	TAM	PREC	RAD	EPd	EPs
Rygge	1981-2010	6.6	14.5	335	17.3	3.3	410
	2070-2099	+2.5	+2.7	-30	-0.4	+0.2	+20
Værnes	1981-2010	6.1	13.1	340	16.1	3.0	374
	2070-2099	+2.4	+2.6	-21	0.0	+0.2	+24
Tromsø	1981-2010	3.2	9.6	297	13.9	2.5	305
	2070-2099	+2.6	+2.2	+7	-0.4	0.0	+8

Table 2. Mean dry matter yields (kg ha^{-1}) and accumulated drought stress (∑(1-Ea/Ep))during three growths per season for baseline and changes for future periods at three sites in Norway. Ea = actual and Ep = potential evapotranspiration from plants, mm d^{-1}.

Site	Period	Yield, kg DM ha^{-1}, per growth:				Drought stress, growth:		
		First	Second	Third	Total	First	Second	Third
Rygge	1981-2010	6,063	3,961	1,268	11,292	7.88	12.06	5.86
	2070-2099	+863	-290	+1,085	+1,658	-5.64	-0.70	+10.98
Værnes	1981-2010	6,056	4,565	1,380	12,001	4.87	7.02	4.03
	2070-2099	+904	-794	+1,645	+1,755	-3.17	+2.29	+5.31
Tromsø	1981-2010	6,000	3,359	0	9,359	4.90	6.91	0
	2070-2099	-49	+1,911	+111	+1,973	-3.82	+1.74	+0.64

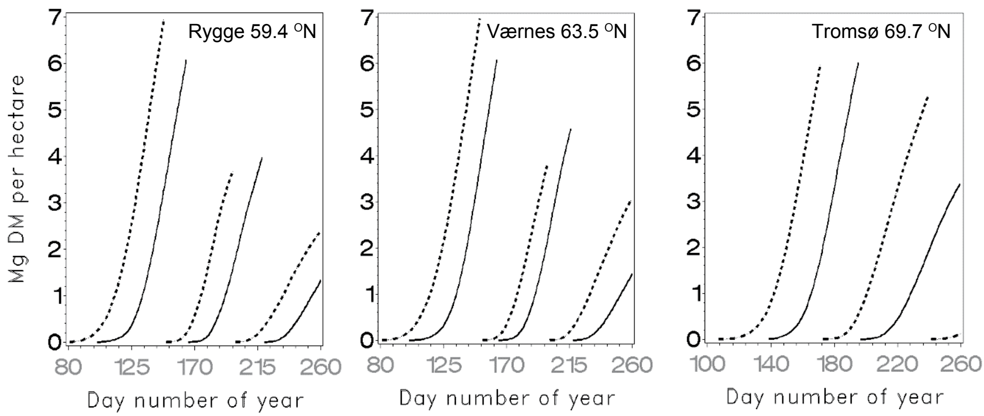

Figure 1. Model estimated dry matter yields in tonnes per hectare at sites of increasing latitudes, means for the periods 1981 - 2010 (——) and 2070 - 2099 (----).

Discussion

In the estimates above, harvest time is determined according to a fixed scheme. Due to the use of a 30 year period, we think that our estimations of *the change* from present to future climate would not be very different if the harvest days had been determined from grass growth, development and the weather and managerial situation for each year.

The increase of yields in the first harvest at Rygge and Værnes (Table 2) is to be expected and is associated with reduced drought stress. Thus, it is somewhat surprising with no increased first yield at Tromsø, also showing reduced drought stress. In central and south-eastern Norway, the second grass growth will nearly always be restrained by more or less severe drought. In a future climate, drought stress at Værnes increased, and second growth yields at Værnes and Rygge became more equal. Even at Tromsø, some drought stress occurs during second growth, most pronounced in the future. But an appreciable future increase in growth potential was to be expected. The third harvest at Rygge and Værnes will be approximately doubled in the future climate as compared with the present one despite an appreciable increase in the already high drought stress. It should be emphasised that the second and third yield estimates are especially uncertain due to the fact that late summer growth depression is extremely difficult to estimate.

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Herbage legumes enhance soil fertility in crop rotation

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Abstract

Herbage legumes are cultivated for various purposes: forage and raw material production for bioenergy or green manuring. Soil fertility improvement is a key objective; however, its extent depends on how the herbage is managed. A field trial was conducted with six herbage legume species to determine their biomass production, distribution and chemical composition. Red clover yielded the most biomass (14.9 t ha^{-1}) with spring growth, regrowth and roots containing 322 kg N, 6,474 kg C, 42 kg P and 279 kg K ha^{-1} by the end of second growing season. Alsike clover attained similar yields. Of the common green manure crops, white sweet clover returned significantly more C (108.8%) and K (148.3%) than bigleaf lupine to the soil. Of the annuals, berseem clover had biomass (7.59 t ha^{-1}), N (161 kg ha^{-1}) and C (3,336 kg ha^{-1}) production in the seeding year that was half that of red clover. Lupine is distinguished by its biomass allocation to roots and stubble (52%). In other species, the plants' aboveground biomass (spring and regrowth) yielded 74.9-91.9% of the biomass. In pursuit of soil fertility improvement, red clover is a suitable pre-crop for spring cereals and its entire biomass should be ploughed in.

Keywords: red clover, Alsike clover, bigleaf lupine, white sweet clover, crimson clover, berseem clover, biomass

Introduction

Producers specialising in plant husbandry should cultivate herbage legumes in a crop rotation in order to enhance soil fertility and crop productivity. In Estonia, the following species are deemed suitable: red (*Trifolium pratense* L.), Alsike (*Trifolium hybridum* L.), crimson (*Trifolium incarnatum* L.), berseem (*Trifolium alexandrinum* L.), white sweet clover (*Melilotus albus* Medik.) and bigleaf lupine (*Lupinus polyphyllus* Lind.). The aboveground biomass of clovers can be used as nutritious forage and the herbage of sweet clover and lupine is a potential raw material for biogas production (Kryzeviciene *et al.*, 2008; Hensgen and Wachendorf, 2016). Thus, there are two options how these species that can be exploited for the maintenance and enhancement of soil fertility: either whole or just a proportion of grown biomass (roots) can be ploughed in. Leguminous green manuring crops precede winter or spring cereals in rotation. For winter crops, the biomass is ploughed in early August in Estonia, for the spring crops in mid-October. The objective of this research was to examine the suitability of six leguminous species for green manuring, their capacity to form biomass, their above- and below-ground distribution of biomass and to quantify the stock of nutritional elements available for ploughing into the soil in October.

Materials and methods

A field trial conducted at the Estonian Crop Research Institute included the following cultivars: (1) red clover 'Jõgeva 433' (2n), (2) Alsike clover 'Jõgeva 2' (2n), (3) bigleaf lupine 'Lupi', (4) white sweet clover 'Kuusiku 1', (5) crimson clover 'Contea' and (6) berseem clover 'Alex'. The first three are perennial species, sweet clover is biennial and the latter two are annuals. The species were sown without a cover crop in pure stand using a drill space of 15 cm, except for the bigleaf lupine (30 cm drill space). Each species was sown in a field of area 432 m^2. Half of the area was ploughed in early August (Bender *et al.*, 2017) and the other half in mid-October. The plots for the biomass and root studies were allocated randomly on both halves of the experiment in four replicates. Biennials and perennials were sown in July 2011, annuals in April 2012. The seeding rates were: red clover, 11 kg ha^{-1}; Alsike clover, 8.8 kg ha^{-1}; bigleaf lupine, 25 kg ha^{-1}; white sweet clover, 24 kg ha^{-1} and annual clovers, 25 kg ha^{-1}. Neither mineral nor organic fertilisers were applied. The trial was situated on calcaric cambisol (K_0) soil, with the following agrochemical indices: pH 6.7, phosphorus (P) 65 mg kg^{-1}, potassium (K) 102 mg kg^{-1}, calcium (Ca) 4,157 mg kg^{-1}, organic carbon (C_{org}) 35 g kg^{-1} and total nitrogen (N) 2.6 g kg^{-1}, clayish loam in texture. In biennial and perennial species, the aboveground biomass was harvested and weighed at full bloom on 6 July with a forage harvester Hege 212. The early-maturing lupine was harvested on 20 June. Thereafter, the fresh herbage was crushed, spread and left on the field. Before ploughing, the regrown biomass was weighed in October for all species. Table 1 summarises the harvested aboveground biomass of spring and regrowth. In annual clovers, the spring growth was ploughed into the soil. The roots (hereafter with stubble) were sampled from within a ploughed layer 25 cm deep from an area of 15 cm × 30 cm. Plant roots were washed on a sieve with a mesh size of 2 mm × 2 mm, dried and weighed. All measurements were replicated four times. Table 1 presents the dry matter (DM) production. The contents of N, C_{org}, P and K were analysed from the DM of herbage and roots. Data analyses (ANOVA and Fisher's LSD) were performed using statistical package Agrobase 20™.

Results and discussion

At the end of the second growing season, the amounts of ploughed biomass, C and nutrient stocks of red clover surpassed the other species (Table 1). Spring growth, regrowth and roots yielded 14.92 t ha^{-1} DM with 6,474 kg C, 322 kg N, 42 kg P and 279 kg K sampled in the soil. The aboveground portion of biomass comprised 75.1% of the total biomass, with corresponding proportions of C, N, P and K being 78, 78, 74 and 86%, respectively. Alsike clover performed similarly to red clover. The superiority of these two species was later affirmed by the gain in grain yields in spring cereals two years after ploughing (Tamm *et al*., 2016). The entire biomass and the stocks of measured elements in bigleaf lupine and white sweet clover were significantly surpassed by red clover. Bigleaf lupine was distinguished from other species by its rapid spring growth and development (full bloom on 20 June) and its biomass allocation. Its roots formed over half (52%) of the entire biomass grown by the end of the second growing season. White sweet clover as a biennial species produced negligible regrowth after the first harvest at full bloom on 6 July. Two and a half months after the first cut, i.e. by October, the roots' biomass had decreased by 31% in sweet clover as regards the amount in August (Bender *et al*., 2017). The dead fibrous roots of the plants decayed in the soil. A risk of nutrient leaching can follow in late summer (Talgre, 2013). White sweet clover was distinguished by higher K stock in the aboveground portion of the plants, when compared with bigleaf lupine. Among the annuals, berseem clover was the most suitable. By October of the seeding year, its total biomass (7.59 t ha^{-1}) and the stocks of C (3,336 kg ha^{-1}) and N (161 kg ha^{-1}) attained nearly a half (and P and K even less) of the respective amounts in red clover.

Conclusion

Of the six studied herbage legumes, red clover was suited to soil improvement by green manuring before the spring cereals. The effect was biggest when beside roots, both spring growth crushed at full bloom and also the regrowth was ploughed into the soil on the second year. The shortcomings of white sweet clover if cultivated for two years are poor regrowth after the first cut, death of the plants in the middle of summer, decomposition of roots in the soil and risk of nutrient leaching in late summer. If the late harvest time of a preceding crop does not allow sowing of perennials, berseem clover can be cultivated as an intercrop in a rotation to manure the spring cereals. Nevertheless, its contribution to soil fertility enhancement amounts to a half of the effect of red clover.

Table 1. Biomass production of herbage legumes (DM, Mg ha^{-1}), its allocation and nutrient stocks (kg ha^{-1}).[1]

	Species	Dry matter	N	C	C : N	P	K
Above-ground biomass	Red clover *(Trifolium pratense* L.*)*	11.20^{a}	251^{a}	5,048^{a}	20	31^{a}	241^{ab}
	Alsike clover *(Trifolium hybridum* L.*)*	10.58^{ab}	245^{a}	4,714^{ab}	21	31^{a}	260^{a}
	Bigleaf lupine *(Lupinus polyphyllus* Lind.*)*	5.77^{c}	121^{b}	2,542^{c}	21	16^{b}	121^{c}
	White sweet clover (*Melilotus albus* Medik.*)*	10.04^{b}	253^{a}	4,556^{b}	18	30^{a}	236^{b}
	Crimson clover *(Trifolium incarnatum* L.*)*	4.20^{d}	83^{c}	1,858^{d}	23	6^{c}	72^{d}
	Berseem clover *(Trifolium alexandrinum* L.*)*	6.40^{c}	138^{b}	2,858^{c}	22	9^{c}	88^{d}
	LSD 0.05	1.07	25	414		3	23
Root biomass in the 0-25 cm soil layer	Red clover *(Trifolium pratense* L.*)*	3.72^{b}	71^{c}	1,426^{b}	20	11^{a}	38^{b}
	Alsike clover *(Trifolium hybridum* L.*)*	3.54^{b}	78^{b}	1,279^{c}	16	11^{a}	37^{b}
	Bigleaf lupine *(Lupinus polyphyllus* Lind.*)*	6.25^{a}	147^{a}	2,329^{a}	16	14^{a}	57^{a}
	White sweet clover (*Melilotus albus* Medik.*)*	1.74^{c}	23^{d}	746^{d}	23	3^{b}	28^{c}
	Crimson clover *(Trifolium incarnatum* L.*)*	0.37^{e}	5^{e}	146^{f}	31	1^{b}	5^{d}
	Berseem clover *(Trifolium alexandrinum* L.*)*	1.19^{d}	23^{d}	478^{e}	21	3^{b}	11^{d}
	LSD 0.05	0.35	7	83		3	8
Total biomass	Red clover *(Trifolium pratense* L.*)*	14.92^{a}	322^{a}	6,474^{a}	20	42^{a}	279^{ab}
	Alsike clover *(Trifolium hybridum* L.*)*	14.12^{a}	323^{a}	5,993^{b}	19	42^{a}	296^{a}
	Bigleaf lupine *(Lupinus polyphyllus* Lind.*)*	12.02^{b}	268^{b}	4,871^{d}	18	30^{b}	178^{c}
	White sweet clover (*Melilotus albus* Medik.*)*	11.78^{b}	276^{b}	5,302^{c}	19	33^{b}	264^{b}
	Crimson clover *(Trifolium incarnatum* L.*)*	4.57^{d}	88^{d}	2,004^{f}	23	7^{d}	77^{e}
	Berseem clover *(Trifolium alexandrinum* L.*)*	7.59^{c}	161^{c}	3,336^{e}	21	12^{c}	99^{d}
	LSD 0.05	0.80	23	374		3	21

[1] Means within each column followed by the same letter are not significantly different according to Fisher's *LSD* test.

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Identifying the drivers of changes in the relative abundances of species in agroecosystems

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Abstract

Increasing species diversity often promotes ecosystem functions in grasslands, but sward diversity may be reduced over time through competitive interactions among species. We investigated the development of species' relative abundances in intensively managed agricultural grassland mixtures over three years to identify the drivers of diversity change. A continental-scale field experiment was conducted at 31 sites using 11 different four-species mixtures each sown at two seed abundances. The four species consisted of two grasses and two legumes, of which one was fast establishing and the other temporally persistent. We modelled the dynamics of the four-species mixtures over the three-year period. The relative abundances shifted substantially over time; in particular, the relative abundance of legumes declined over time but stayed above 15% in year three at many sites. We found that species' dynamics were primarily driven by differences in the relative growth rates of competing species and secondarily by density dependence and climate. Alongside this, positive diversity effects in yield were found in all years at many sites.

Keywords: biodiversity, dynamics, grass, legume, multispecies mixtures, relative growth rate

Introduction

The common practice of managing highly fertilised grassland monocultures has often been critiqued and there is a need for productive grass-legume systems that require less fertiliser and lead to improved environmental outcomes (Lüscher *et al.,* 2014, Suter *et al.*, 2015). There is wide consensus that increasing species diversity promotes many ecosystem functions. Over time, however, some species in a mixture may become dominant at the expense of others and sward diversity may decline, thus reducing the benefits to ecosystem function (Carroll *et al*., 2011). Here, we examine the dynamics of the relative abundances of multiple species in agronomic grassland mixtures and identify reasons why changes occur at the species level across 31 coordinated multi-year experimental sites.

Materials and methods

A common experiment was carried out at 30 sites across Europe and one site in Canada. At each site 22 four-species mixture plots were established. The four species comprised two grasses and two legumes, of which one was fast establishing and the other temporally persistent. Thus, there were four functional groups: grass (G) / legume (L) by fast establishing (F) / temporally persistent (P) which were denoted G_F, G_P, L_F and L_P. The identity of the species within functional groups varied across the sites; yet, there was a total of 11 unique species used across the experiment. At each site, the relative abundances of the four species were varied systematically across 11 mixture plots ranging from each species equally present (25% of each) to one species dominant (70%, 10%, 10%, 10%) and each of the 11 mixtures was sown at two seed abundance levels. Monocultures of each species were also established at each seed abundance level, giving an additional eight plots at each site. N fertiliser was applied at most sites (maximum rate of 150 kg N ha^{-1} annum) and plots were harvested between two and seven times per annum depending on local practice. The annual plot-level biomass of each of the four species was recorded for three years following the year of establishment. Further experimental details are available in Kirwan *et al.* (2007, 2014).

We analysed relative growth rates (Connolly and Wayne, 2005) for each species in mixture to explain changes in relative abundances for sown-year 1, years 1 - 2 and years 2 - 3.

Results and discussion

Across all sites, we found significant changes in the relative abundances of our four-species mixtures over the three years. The main driver of those changes was differences in the relative growth rates of species. On average across all sites, the temporally persistent grass (G_P) become dominant by year 3 (Figure 1) but the relative abundance of G_P in year 3 varied substantially across sites, ranging from 5% at one site to 100% at another (Brophy *et al.*, 2017). The relative abundance of legumes ($L_F + L_P$) was generally high in year 1, and while it declined over time, there were 12 sites that still had average legume abundance above 15% in year three. Legume persistence was positively related to sites' annual minimum temperature (computed as the average of the lowest five annual values) in years 2 ($P = 0.002$) and 3 ($P = 0.003$). Overall, we found several intra- and inter-specific density-dependent dynamics in our multi-species communities, which gave evidence for stabilising processes acting on the system (Brophy *et al.*, 2017). Alongside the substantial shifts in dynamics, Brophy *et al.* (2017) and Finn *et al.* (2013) showed significant positive diversity effects at many sites in all three years, the strengths of which were positively related to legume abundance.

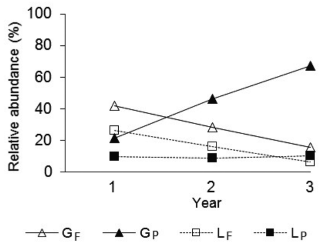

Figure 1. The average relative abundance of each functional group across all sites in each (post-seeding) year. The species are classified according to functional traits: fast establishing grass (G_F) and legume (L_F) and temporally persistent grass (G_P) and legume (L_P).

Conclusion

This continental-scale field experiment showed the importance of the relative growth rates of competing species for community dynamics and species shift over time. Alongside this, significant positive diversity effects were evident across the three experimental years at many sites. Diversity effects in multi-species mixtures can be further enhanced through the inclusion of legumes and strategic selection of the species and their cultivars, paying particular attention to their traits and competitive abilities relative to each other.

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Soil faunal and plant diversity of dairy and semi-natural grasslands on peat

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Abstract

Peat wetlands are of major importance for ecosystem services such as carbon storage and maintenance of biodiversity. However, peat drainage for farming leads to CO_2 emission and biodiversity losses. In the peat areas in the Netherlands, solutions are sought in reducing drainage and converting productive dairy grasslands to less intensively managed semi-natural grasslands. Our objective was to compare the soil faunal and plant diversity of dairy and semi-natural grasslands on peat soils. Taxonomic richness of earthworms, enchytraeids, nematodes, microarthropods and plants were measured in 20 dairy and 20 semi-natural sites. Mean soil faunal taxonomic richness per site (alpha diversity) was higher in dairy grasslands compared to semi-natural grasslands but no difference was found for plant species richness. However, the total observed number of taxa (gamma diversity) in dairy grassland was 21% lower for soil faunal and plant species together. We conclude that spatial scale is of crucial importance for biodiversity and management strategies. In dairy grasslands, between-farm diversification may increase biodiversity at landscape scale. Similarly, diversity in (semi) natural grasslands is needed to keep a high gamma biodiversity in this land use type.

Keywords: grassland, terric histosols, soil biodiversity, botanical diversity

Introduction

Peat wetlands worldwide deliver important ecosystem services such as carbon storage and maintenance of biodiversity. Approximately 80% of the peat area in the Netherlands is drained and used for grassland-based dairy farming. Apart from CO_2 emission and soil subsidence, peat drainage for farming leads to loss of floral and faunal biodiversity, including meadow birds. Current policy, therefore, focuses on increasing the area of (semi-)natural grasslands and promoting 'nature-inclusive' agriculture including reduced drainage (Erisman *et al.*, 2016; Van den Born *et al.*, 2016). However, for effective policy and land management, it is necessary to know how a less intensive land use affects soil functioning. Effects on delivery of several soil-related ecosystem services of dairy and semi-natural grasslands on peat is presented in Deru *et al.* (2018). In the present paper, we focus on biodiversity. Our aim was to provide a comparison of the plant and soil species diversity of peat grasslands either used for grass production or for nature restoration and conservation.

Materials and methods

In the western peat district of the Netherlands, we selected 20 grasslands on dairy farms ('dairy grasslands') and 20 grasslands in areas managed for nature conservation ('semi-natural grasslands'). All grasslands had a minimum sward age of ten years. Dairy grasslands had an average ditch water level of 49 cm below soil surface (Table 1), and a conventional management with a history of mixed grazing and cutting. In the semi-natural grasslands, mean ditch water level was 9 cm higher than in dairy grasslands. Most of the semi-natural grasslands were extensively grazed, cut once or twice a year after the chick season of meadow birds and had low manure input, mainly as solid cattle manure. At each site, an experimental plot was laid out in February 2010, which remained unfertilized, ungrazed and unmown until soil sampling in April 2010. In each plot, nematodes, enchytraeids, earthworms and microarthropods were sampled and identified as described in Deru *et al.* (2018). Botanical composition was assessed in June 2010 according to the Braun-Blanquet cover-abundance method. Statistical analysis was carried out in Genstat (18th edition), using a one-way ANOVA to test for land use effect ('dairy' versus 'semi-natural'). Additionally, gamma diversity was calculated as the sum of taxa found in all samples per land use type. Full method description can be found in Deru *et al.* (2018).

Results and discussion

The mean number of plant species did not differ between grassland types (Table 1). However, plant gamma diversity in dairy grassland was lower than in semi-natural grassland: 34 vs 64, respectively (Figure 1).

Soil faunal taxonomic richness was higher in dairy than in semi-natural grasslands. Mean earthworm abundance of dairy grasslands was about twice that of semi-natural grasslands. At the scale of grassland, positive influence of nutrient input on soil biodiversity and a lack of correlation between aboveground and belowground biodiversity is in line with studies of grasslands on clay soils (Van der Wal *et al.*, 2009). Dairy grasslands have a higher input of easily decomposable organic matter to the soil via manure and primary production (plant residues, root exudates), next to drier (thus also warmer) soil conditions in spring due to drainage. These factors together may contribute to a higher abundance and diversity of soil biota (Cole *et al.*, 2005; Plum and Filser, 2005; Yeates, 1987).

Table 1. Management and biodiversity of 20 dairy and 20 semi-natural grasslands on peat.

Parameter	Unit	Dairy		Semi-natural		*P*-value
		mean	s.d.	mean	s.d.	
Management						
Ditch water level (summer)	cm below soil surface	49	8	40	14	0.009
N from organic manure	kg N ha^{-1} yr^{-1}	216	55	43	50	< 0.001
Biodiversity						
Monocotyledon soil cover	%	82.5	10.6	55.1	21.1	< 0.001
Number of plant species	N	15.2	3.2	14.8	5.3	0.104
Number of soil faunal taxa	N	71	4	61	12	< 0.001

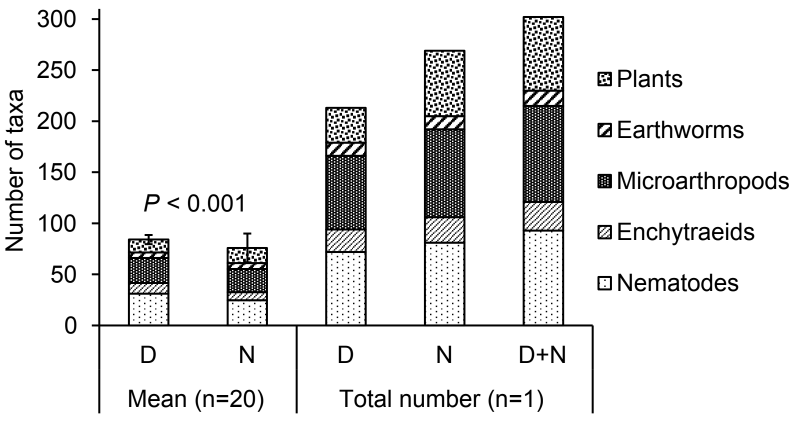

Figure 1. Number of plant and soil faunal taxa in dairy (D) and semi-natural (N) grasslands on peat: grassland mean (alpha diversity) and total number (gamma diversity) (adapted from Deru *et al.* (2018)).

In contrast, the soil faunal gamma diversity was higher in semi-natural grassland: of the 230 taxa found in all 40 sites, 78% was present in dairy grasslands and 89% in semi-natural grasslands (Figure 1). The difference in gamma diversity indicates that the botanical and soil faunal taxonomic composition was more homogeneous across dairy grasslands and more diverse across semi-natural grasslands. This could well be related to a lower diversity in land management of dairy grasslands. Our findings have implications for nature conservation in managed peat areas at field and landscape scale. First, the trend towards low between-farm diversity should be reversed. Second, the lower diversity of individual semi-natural grasslands (alpha diversity) may imply that many (semi-)natural grasslands are needed to increase the total nature value. Finally, our results emphasise the importance of considering spatial scale when evaluating ecological observations.

Conclusion

Spatial scale is of crucial importance in maintaining biodiversity and considering biodiversity strategies. In dairy grasslands, diversification in management between farms may increase biodiversity at a larger geographical scale. Similarly, diversity in types and management of (semi-) natural grasslands is needed to keep a high biodiversity at landscape scale.

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Alpine pasture vulnerability and adaptation strategies to climate change: the LIFE PASTORALP project

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Abstract

As one of the most sensitive ecosystems to climate change and human disturbances, Alpine permanent grasslands have been identified as hotspots of climate and land-use changes. The LIFE project PASTORALP (Pastures vulnerability and adaptation strategies to climate change impacts in the Alps; www.pastoralp.eu) combines biophysical and socio-economic approaches to address the vulnerability of Alpine pastures and provide a better capacity to reduce climate change impacts. The project relies on a solid science-based knowledge of baseline conditions of Alpine pastoral communities and projected impacts of future climate changes on these same communities, with focus on two national parks representative of West's Alpine environments: *Parc National des Écrins* (France) and *Parco Nazionale Gran Paradiso* (Italy). Stakeholder consultation and engagement will be a core element of the project work plan. The final output will be the deployment of platform tools facilitating the adoption of adaptation strategies in the two parks, aligned with the objectives of the 'Climate change adaptation priority area' of the EU. These new strategies and tools could be easily exploited in other pastoral areas across the Alps.

Keywords: alpine pastures, management tools, protected areas, land use, vulnerability assessment

Introduction

Climate change and its impacts are already visible globally. Over the last century, the Alpine region has experienced a temperature increase of about 2 °C and variations in precipitation patterns (EEA, 2009). Alpine pastoral ecosystems are threatened by both anthropogenic activities and environmental changes, mainly climate change (Subedi *et al.*, 2016), increasing their vulnerability (IPCC, 2014). Studies indicate that these changes likely alter grassland productivity and quality (Targetti *et al.*, 2010), harm cold-tolerant high-altitude grassland communities (Gottfried *et al.*, 2012) and can lead to a decline of the areas suitable for some vegetation types (Dibari *et al.*, 2013). Moreover, land abandonment and depopulation phenomena have determined relevant changes in mountain ecosystems and depletion of plant species richness (Orlandi *et al.*, 2016).

Appropriate management can preserve grassland biodiversity, maintain ecosystem services and counteract climate change impacts (Nori and Gemini, 2011; Felber *et al.*, 2016). However, in many Alpine regions, specific measures to manage pastures coping with climate change are still not implemented, despite the adoption of *ad hoc* policies (e.g. European Agricultural Policy, Dir. 2001/41/EU, Reg. 2003/1782/EU and 2005/1698/EU).

The LIFE project PASTORALP ('Pastures vulnerability and adaptation strategies to climate change impacts in the Alps') aims to fill this gap by combining biophysical and socio-economic characteristics to address the vulnerability of Alpine natural pastures and providing a better capacity to reduce it. PASTORALP, co-funded by the EU LIFE program (started October 2017), relies on a science-based knowledge of baseline conditions of Alpine pastures and projected impacts of future climate changes on these plant communities. Following this approach, the project is focusing on vegetation and management situations of two parks representative of West's Alpine environments. (Figure 1): *Parc National des*

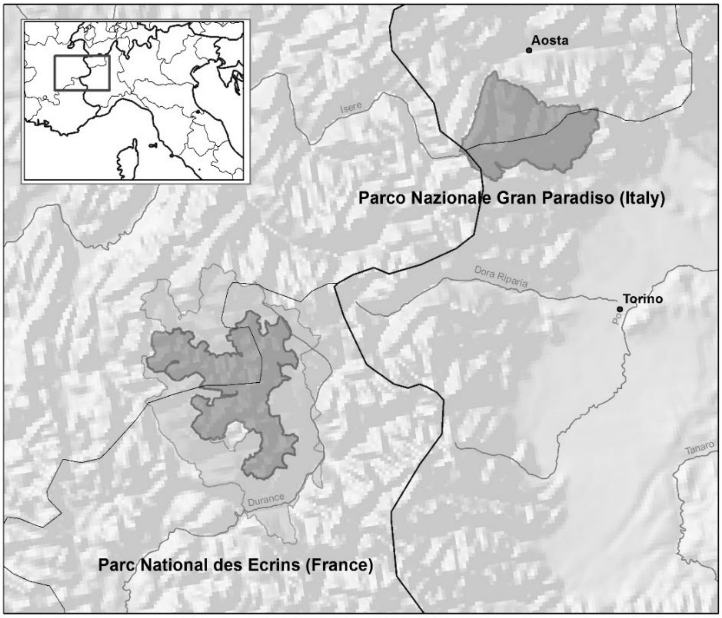

Figure 1. Location of the two case study areas *Parc National des Écrins* and *Parco Nazionale Gran Paradiso*.

Écrins (France) and *Parco Nazionale Gran Paradiso* (Italy), total rural population: 24,000; total surface: 162,000 ha.

Materials and methods

Key cross-sectoral issues will be addressed by considering both rural socio-economy and biodiversity and by identifying and promoting ecosystem-based adaptation solutions, evaluated against environmental, technical, economic and social criteria. The structure of the project consists of eight implementation actions, which are closely interconnected. First, activities will be directed to the quantitative assessment of baseline conditions of natural pastures in the two study areas. This will regard the review of current national and European policy frameworks on pastures and climate change adaptation so as to identify best current techniques and methods implemented worldwide. Further, high-resolution climate data for the study areas will be produced under future scenarios, to input models, calculate vulnerability indicators and identify improved and feasible adaptation strategies in grassland management in the future. Concurrently, grassland types of the two parks will be inventoried (through remote sensing, modelling and field surveys) and mapped. To assess the impact of climate change on integrity and functioning of Alpine pastoral systems, a comprehensive vulnerability analysis (economic, social and biophysical) will be performed based upon an indicator-based scheme and a modelling approach. Process-based models (PaSim and DayCent) and economic models (spatially-explicit and multivariate logistic regressions) will be used to: 1) identify evolution of pastoral resources under future climate scenarios and 2) estimate statistical relationships between grassland changes and socio-economic and policy conditions influencing farmers' decisions. Finally, feasible adaptation strategies will be identified, tested in pilot areas and refined under an iterative process, entailing feedback from local stakeholders, involved during the project life.

Results and discussion

The main expected outcome of the project will be the deployment of web platform tools to support the adoption of adaptation strategies in the two parks. This platform will act as an online repository of the project's outcomes, intended to: 1) create synergies with the EU Strategy on adaptation to climate change, 2) provide guidance to integrate feasible adaptation strategies on mountain pastoral resources into the CAP and RDPs, and 3) build up capacities for adaptation. Moreover, two permanent demonstration areas will be settled in the two parks to increase awareness on climate change and the associated risks, adopt specific adaptation measures through 'real-life' experiences and ensure a wider exploitation of the proposed methodology to other pastoral areas. An increased capacity of local communities for coping with climate change impacts on pastures and related adaptations will also be a relevant outcome of the project.

Conclusion

LIFE PASTORALP, through the assessment of the vulnerability of pastures to climate change and the proposal of new management techniques addressing adaptation, will ensure the sustainability and feasibility of outstanding practices, methodologies and proofing policies for grassland management in Alpine protected areas and also across the entire Alps.

Acknowledgements

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Does sward management affect carbon storage under upland permanent pasture?

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Abstract

Soil is the largest terrestrial sink for atmospheric carbon. In the UK, almost a third of soil organic carbon (SOC) is found in the uplands. Research in the uplands has focused on peat as a carbon sink. Other research has explored changes between land use types, such as pasture, forestry and arable systems. Management within a land-use type, for example, which has an effect on carbon storage in grasslands, is less well understood. Using the Brignant plots, established in 1994 to explore the legacy of low intensity management in upland pastures, soil organic carbon (SOC) was estimated using an equivalent soil mass (ESM) methodology. Because it does not rely on fixed depths, the ESM method can be useful to calculate SOC in soils where sampling to a fixed depth is difficult when impeded by rocky, thin soil, or other obstacles, making it useful at Brignant where soil depth is variable and very stony. Management treatments are: grazing only, hay-cutting only and hay-cutting with aftermath grazing; all with and without liming. A grazed control treatment which has N, P, K and lime added as per industry best practice runs alongside. This study describes the use of ESM to determine SOC levels between a range of management options in an upland fringe-pasture setting.

Keywords: soil, carbon, grassland, uplands, fringe-pasture

Introduction

Soils represent the largest terrestrial sink of atmospheric carbon (Guo and Gifford, 2002). Globally, nearly half (40.5%) of these soils are under grassland, representing an important component of the terrestrial carbon budget. Almost a third of SOC in the UK is found in the uplands (Smith *et al.*, 2014). Comparisons of soil carbon stocks between land-use types are well represented (Keith *et al.*, 2015), and conversion from forest to farmland can reduce SOC by 20 - 50%, while conversion from arable to grassland can increase SOC by up to 19%, (Conant *et al.*, 2001). Within a single land use, the effects of management change are less well understood. It is thought that the legacy effects of land use can persist for years, if not decades or more from the point of change (Smith, 2014), yet the paucity of data from long-term studies means that there is less information available on the strength and direction of these effects. The objective of this study was to examine the legacy of long-term extensification on SOC in marginal upland soils and to establish the extent to which management can play a role in conserving soil carbon stocks in upland fringe-pastures.

Materials and methods

The Brignant plots were set up in 1994 to explore the long-term effects of extensification in an upland setting and are situated 15 miles inland of Aberystwyth (O.S. Ref: SN752757), at 310 m a.s.l. The soil is a free-draining podzolic brown-earth; composition is about 20% sand, 58% silt and 22% clay. The plots are 0.15 ha in size (except for the hay-cut only plots which are 0.08 ha). Treatments were replicated with three blocks containing randomly allocated treatment types. A control plot within each block is grazed only and receives annual inputs of NPK fertiliser to a target rate of 60 kg N ha^{-1} and 30 kg P ha^{-1}, with occasional dressing of K to maintain background levels. Lime is applied as required to maintain a pH above 6. Other treatments were: grazing only, hay-cut only and hay-cut with aftermath grazing, each with and without the application of lime, but no fertiliser (Gr+ & Gr-, Hay+ & Hay- and Hay/Gr+ & Hay/Gr- respectively).

Grazing was from April/May until August/September, depending on biomass availability. Hay plots are mown in late July. Hay/Gr plots are cut on the same date and then grazed until September/October. For soil carbon assessment, IPCC guidelines (IPCC, 1997) suggest a uniform sampling depth of 30 cm, but this is not always possible where soil is thin or very stony. An equivalent soil mass (ESM) methodology has been developed by Gifford and Roderick (2003) as a means of estimating soil carbon after land-use change. This approach is mass rather than spatially based, and is generally used where changes in soil bulk density may otherwise affect the results. Since it does not require a fixed sampling depth, ESM is useful where these are difficult to obtain. In August 2016, based on this methodology soil, cores were taken from each plot using a split corer, resulting in a total of 210 samples. Target sampling depth was 30 cm, in three divisions 0 - 7.5, 7.5 - 15 and 15 - 30 cm. Any cores reaching a min of 13 cm (total length) were used in the analysis. Samples were analysed for soil carbon and nitrogen using an elemental analyser (Leco Truspec CN, Milan, Italy). Measures for soil moisture (g water g^{-1} soil), bulk density (g cm^{-3}) and soil pH were taken as part of the wider experiment (Table 1). Only organic carbon (%) and soil oven-dry weight (g $core^{-1}$) were used in the ESM calculation, other variables will be summarised only. Soil organic carbon was analysed from ESM data and the results were analysed using analysis of variance in IBM SPSS Statistics for Windows, version 24 (IBM Corp., Armonk, N.Y., USA).

Table 1. Summary of mean values and standard errors (in brackets) for the main variables examined. Except for SOC, which uses the whole core value in the calculation, all values are for the top 7.5 cm layer only.

Treatment	SOC (ESM) kg m^{-2}	Nitrogen g kg^{-1}	Water g g^{-1} soil	pH	Bulk density g cm^{-3}	C:N ratio
Control	3.94 (0.9)	81 (26)	0.89 (0.2)	5.7 (0.6)	0.49 (0.1)	10:1
Gr+	4.31 (0.8)	75 (21)	1.06 (0.4)	5.7 (0.3)	0.48 (0.1)	12:1
Gr-	4.21 (0.7)	55 (9)	0.80 (0.1)	5.1 (0.4)	0.56 (0.1)	12:1
Hay+	3.93 (0.9)	58 (9)	0.98 (0.2)	5.9 (0.4)	0.48 (0.1)	12:1
Hay-	4.31 (0.6)	62 (8)	0.96 (0.2)	5.0 (0.4)	0.54 (0.1)	11:1
Hay/Gr+	4.35 (0.6)	66 (9)	1.05 (0.2)	5.3 (0.6)	0.50 (0.1)	11:1
Hay/Gr-	4.23 (0.7)	63 (5)	0.95 (0.2)	4.8 (0.6)	0.53 (0.1)	11:1

Results and discussion

There was no significant effect of treatment on SOC levels ($F_{6,\ 205}$ = 2.084, P >0.05) (Table 1). Management alone is not enough to have a significant impact on the level of organic carbon retained within the soil profile.

Conclusion

The management treatments in this study did not have a significant impact on the carbon storage under permanent pasture in the uplands, suggesting that for the purposes of carbon stock assessment, they can be grouped together irrespective of management methods. In determining causes of variation between swards, it may be more useful to look at topological features such as elevation, slope and aspect, as well as soil type and moisture content.

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Climate sensitivity of Hungarian grasslands

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Abstract

We tend to build a complete grassland database for a complex, governmental decision support system (Hungarian Complex Grass Management Database-HCGMD) at public administration. Supporting this system we need to determine the exact location and extension of grasslands with remote sensing and data mining methods. Hungarian grassland categorization has been merged and unified, based on ÁNÉR (National Habitat Classification System), MÉTA (Hungarian Habitat Spatial Database) and CORINE (Coordination of Information on the Environment) land cover databases. Grasslands have been classified in accordance with climate sensitivity. Classification includes potential yields, reaction on severe weather (drought and flood) and utilization (grazing or cutting). Grasslands have been divided into 18.8% *less sensitive*, 51.7% *moderately sensitive* and 29.5% *very sensitive* categories. The largest grassland coverage is at the Northern Great Plain and East-Outer-Somogy region where grassland usage is the most dominant. We have collected 30 herbage samples from different regions to verify yield estimation (based on remote sensing data) and concluded that featureless, moist meadows *and* swards with tall oat-grass (*Arrhenatherum elatius*), produced the highest yields (DM 7-8 t/ha). According forage quality (K-value), the worst quality grass has grown at Molinietum fen-meadows, open Pannonic sand lands and steppe meadows.

Introduction

Agricultural policy urges solutions which help to mark out drought affected areas. Our grassland classification will be a part of the national cadastral database. We defined the most endangered grassland types in Hungary. Alongside the forestry registry, this classification helps to create long term plans to utilise drought affected rangelands. Along Hungarian land registry this could be a useful tool to help farmers planning ahead with their pastures (Diaz Fernandez *et al.*, 2016). Adaptation to severely hot summers and dry springs is fundamental for pastured beef cattle. Heat tolerance has relatively high heritability (h^2 = 0.13-0.17; Salama *et al.*, 2016) and traditional cattle breeds have been selected for this trait for centuries (Halasz *et al.,* 2016).

Materials and methods

We attempted to merge similar databases like HSO (Hungarian Statistics Office), national land cover information (CORINE 50), MÉTA database (Molnar *et al.*, 2008) and consider a national yield estimation system as well (Gaal *et al.*, 2017). During the 2015 vegetation period we conducted coenological assessment and yield estimation at 30 sites. The recordings were performed under Balazs-method protocol (Balazs, 1949). We categorised plants in seven groups: beneficial grasses, beneficial legumes, other monocots, other dicots, stinging plants, mosses, shrubs. Coverage values were specified in percentage (b%) for each categories. Plant height was also measured. Yield estimation (kg) was based on three-dimensional recording, in 2 × 2 quadrates, with the following formula:

$((M-s)*b*B) / 100 = yield\ (kg\ ha^{-1})$, where (M) = average calculated height weighted by dominance (cm); (s) = stubble height (cm), (b) = coverage %; (B) = biomass with 100% coverage, cross-section of 1cm height sward's green mass weight in kg ha^{-1} 1 cm^{-1} (400 kg ha^{-1} 1 cm^{-1}).

Calculation of utilisable yield

Individual plant species yield value (T) was calculated as follows:

T = D_B^* × average height (cm) (*D_B = Balazs-dominance is a numerical value between 0 and 32. Represents each species dominance in a 2 × 2 m quadrat.)

Yields are also categorised according to edibility:

- edible by animals, valuable plants (+t)
- none edible by animals, none valuable plants (-t). The yield estimation value has been weighted with +t and –t percentages. Eventually this produced the potential utilisable forage. The sward quality indicator (K): T value is multiplied by the plant's feed quality (between -3 and +7 for each species) to produce the *k*t* value. The formula: K = 100 * (∑k * t) / ∑T, where the K-values represent quality classes (Balazs, 1960), as follows: I. (excellent) 4 <; II. (good) 3 - 4; III. (medium) 2 - 3; IV. (fair) 1 - 2; V (poor) 1 >.

Results

The largest grassland coverage is at the Northern Great Plain and East-Outer-Somogy region where grassland usage is the most dominant. The plain, moist meadows and swards (E1) with tall oat-grass (*Arrhenatherum elatius*), produced the highest yields 10 t ha^{-1} of dry matter. According to forage quality (K-value), the lowest quality grass was in *Molinietum* fen-meadows (D2), open Pannonic sand lands (G1) and steppe meadows (F).

We also made climate sensitivity categorisation, based on farm practice, sampling data (Nagy and Tasi, 2017) and yield estimation throughout vegetation period. Grassland habitat type was referred climate sensitive when + or - 30% yield alteration was observed, relative to the average annual yield. We concluded that the most sensitive grasslands are the *Cynosurion* grasslands and *Nardus* swards (E34), calcareous rocky steppes (H2), and uncharacteristic dry and semi-dry grasslands (OC). Comparing with aridity zones (Figure 1), it is obvious that climate sensitivity is in strong relation with soil water supply.

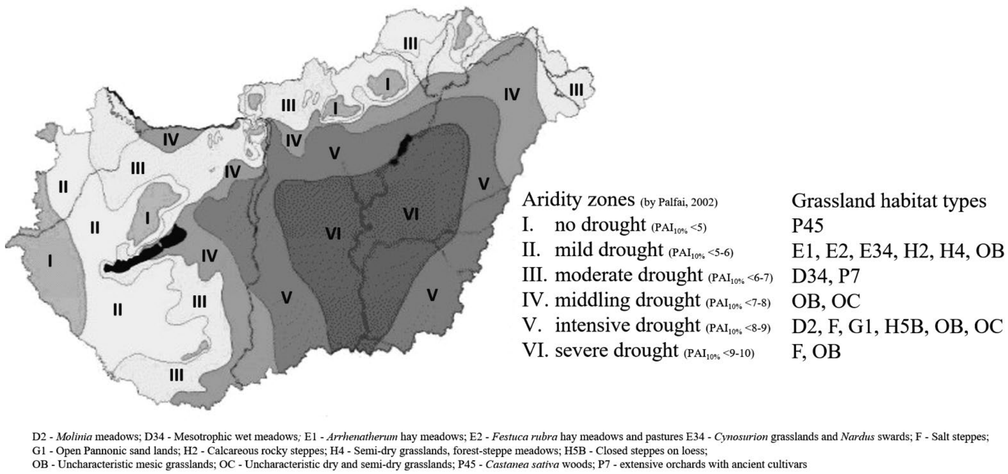

Figure 1. Aridity zones (Palfai, 2002) and sampling sites' grassland habitat types.

Climate sensitivity categories in Hungary

1. Extremely sensitive grasslands: according to the National Habitat Classification System (Á-NÉR, 2011) E34 (*Cynosurion* grasslands and *Nardus* swards), H2 (Calcareous rocky steppes), and OC (Uncharacteristic dry and semi-dry grasslands) habitat types are threatened most. Most of these areas – in the case of sheep grazing – are endangered by the invasive yellow bluestem (*Bothriochloa ischaemum*). The potential utilisable yield is between 3 - 4 t ha^{-1} dry matter. Depending on the weather, yield fluctuation is very large. Drought effect is drastic. The sward is sparse and makes way for erosion and weeds (*Bothriochloa ischaemum*). The forage quality strongly decreases.
2. Very sensitive grasslands: from a farming perspective three different yield-subcategories exist:
   a. 2 t ha^{-1} DM, dry, plain grasslands. The Great Plain steppe meadows (puszta) not counting the lower parts (rich fens). Salt steppes (F) and closed steppes on loess (H5B). Sheep grazing endanger the sandy steppe meadows because of yellow bluestem. Forage quality is fair-medium, locally could be good.
   b. 3 t ha^{-1} DM, dry grasslands. Open sand steppes (G1) habitat belongs here. Better yields, still climate sensitive, medium quality.
   c. Mountainous grasslands on northern and eastern slopes. The expected dry matter is around 4 - 5 t ha^{-1} depending on weather. In average years, first cut produces quality hay. During droughts, at mid-summer burn out is usual. Relatively large yield-fluctuation. The quality is good, medium in drought years. Bigger proportion of legumes compared with other habitats. Categories such as *Festuca rubra* hay meadows and pastures (E2), semi-dry grasslands, forest-steppe meadows (H4), uncharacteristic mesic grasslands (OB), wood pastures and *Castanea sativa* woods (P45) and extensive orchards with ancient cultivars (P7) habitats belong to this group.
3. Moderately sensitive grasslands: situated at the lower parts of the Great Plain *Molinia* meadows (D2). The dry winters and springs favour the utilisation due to the shorter water coverage. First cut can be made earlier. Forage quality is poor (especially the first cut). The yield is around 4 - 5 t ha^{-1} hay.
4. Least sensitive grasslands: meadows in valleys. Mesotrophic wet meadows (D34) and *Arrhenatherum* hay meadows (E1) are in this category. Potential yield is around 10 t ha^{-1} DM, best swards for mowing. Tall grass proportion is high, biodiversity is lower than other categories. Legumes grow better in the second growth because of better water supply. The forage quality is good or excellent.

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Effect of silage harvest date and fertiliser rate on modelled N_2O and total greenhouse gas emissions from pasture-based suckler beef systems

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Abstract

The objective was to determine the effect of fertiliser application rate and silage harvest date on N_2O emissions and sustainability of pasture-based suckler beef systems. A hybrid bio-economic and greenhouse gas (GHG) model was used to determine the economic performance and N_2O emissions of each scenario. The model was modified using new methods to quantify grass N composition and cattle N excretion, and recent country specific N_2O emissions factors (EF). Intensive and extensive bull/heifer and steer/heifer suckler systems were chosen as baseline scenarios. Baseline scenarios were simulated at different silage harvest dates and fertiliser application rates. The research systems footprints ranged from 15.97 to 19.00 kg CO_2e kg^{-1} carcass weight (CW). This was lower than previous estimates and the EU average of 22.2 kg CO_2e kg^{-1} CW. Profit ha^{-1} and kg N_2O kg^{-1} CW increased with fertiliser application rate. Conversely, profit ha^{-1} reduced while kg N_2O kg^{-1} CW increased with later silage harvest date. Bull/heifer systems emitted less kg N_2O kg^{-1} CW than steer/heifer systems. Extensive bull/heifer systems with a higher level of fertiliser application and early silage harvest were the most sustainable. The study found the modifications made to the model significantly improved the understanding of the effect of management practices on the sustainability of suckler to beef production systems.

Keywords: nitrous oxide, greenhouse gas emissions, suckler to beef, whole farm modelling

Introduction

It has been reported by van Groenigen *et al.* (2005) that managed grasslands emit higher levels of N_2O than arable and un-managed land due to the increase in available N in soils. This is of particular concern for pasture-based countries like Ireland where 82% of agricultural land is devoted to permanent grassland. Consequently, as pastoral based ruminant livestock production is ubiquitous, grazing and fertiliser related N_2O emissions have an impact on the agricultural sectors greenhouse gas (GHG) emissions. A number of grassland management factors such as regrowth period, grass maturity at silage harvest and fertiliser application rate are effective in manipulating the quality and N content of grass based diets. Therefore, grassland management practices affecting such factors may offer potential to reduce N_2O emissions from livestock systems. The objective of this study was to determine the effect of the management practices of first cut silage date and fertiliser application rate on N_2O emissions from pasture-based suckler systems. The effect of these management practices on total GHG emissions, profitability and sustainability were also investigated.

Method and materials

A whole farm modelling approach was taken using both the Beef Greenhouse Gas Emission Model (BEEFGEM) model and the Grange Beef System Model (GBSM) model where various components of both were allowed to interact creating a hybrid model. The model included GHG emissions (CO_2, CH_4, and N_2O) associated with the off-farm production and transport of imported farm inputs (e.g. fertiliser) and the on-farm production of feed and animals. Carbon sequestration and post farm animal processing emissions were excluded. Modifications were made to the models to make them more representative of Irish pasture-based suckler systems. Such modifications comprised the inclusion of new insights into animal nutrition and environmental losses. For animal nutrition, grass composition, grass quality, livestock N partitioning and N excretion data and algorithms were updated. For the environmental model, recently developed country specific direct N_2O emission factors (EF) for manure deposited onto pasture and synthetic N fertiliser applications were included. The baseline scenarios modelled were spring calving steer/heifer (SH) and bull/heifer (BH) suckler to beef production systems on two grassland management systems: Intensive (INT) and Extensive (EXT) as described by (Drennan and McGee, 2009). To determine the effect of fertiliser application rate and silage harvest date on N_2O emissions, each baseline scenario was simulated at early and late silage harvest dates (5 May, 28 June) and low (50 - 125kg N ha^{-1}) and high (100 - 250 kg N ha^{-1}) fertiliser application rates. The hybrid model determined total GHG (on and off-farm GHG emissions) and N_2O emissions in CO_2 equivalent (CO_2e) kg^{-1} carcass weight (CW). The model also reported net margin ha^{-1}. Emission intensity and economic performance were simulated simultaneously to calculate emission efficiency (€ net margin t^{-1} N_2O in CO_2e) and to determine the sustainability of the scenarios examined.

Results and discussion

For BH and SH systems, total GHG emissions ranged from 15.79 – 18.39 kg CO_2e kg^{-1} CW and 16.69 – 19.78 kg CO_2e kg^{-1} CW, respectively (Table 1). Similar to the findings of Foley *et al.* (2011), BH systems consistently emitted lower total GHG emissions and N_2O kg^{-1} CW than SH systems when operating at similar intensities (i.e. INT or EXT). This was because bulls have a higher carcass average daily gain (ADG) potential relative to steers (Drennan and McGee, 2009) (Table 1). This reduced average cattle finishing age and allowed the BH system to operate at a higher stocking rate. INT scenarios consistently emitted higher total GHG emissions than EXT scenarios. Scenarios applying high fertiliser rates emitted higher GHG emissions kg^{-1} CW than scenarios applying low fertiliser rates. Regarding silage harvest date, scenarios harvesting on 5 May emitted less GHG emissions kg^{-1} CW than scenarios harvesting on 28 June. The carbon footprints for all scenarios were significantly less than the carbon footprints reported by previous Irish studies (Foley *et al.*, 2011). This was largely explained by the inclusion of recent country-specific EF for manure deposition onto pasture (Krol *et al.*, 2016) and fertiliser application (Harty *et al.*, 2016), where unlike the previous EF they account for the effect of environmental conditions, fertiliser types.

Table 1. Total GHG (kg CO_2e kg^{-1} CW), N_2O (kg CO_2e kg^{-1} CW), farm net margin (€ ha^{-1}) and emission efficiency (€ kg N_2O^{-1}) of Intensive (I) and Extensive (E) steer/heifer (SH) and bull/heifer (BH) systems a = 5th May and high fertiliser rate (100 - 250 kg N ha^{-1}); b = 28 June and high fertiliser rate (100 - 250 kg N ha^{-1}); c = 5 May low fertiliser rate (50 - 125 kg N ha^{-1}); d = 28 June low fertiliser rate (50 - 125 kg N ha^{-1}).

	Total GHG	N_2O	Farm net margin	Emission efficiency		Total GHG	N_2O	Farm net margin	Emission efficiency
SHI a	19.3	3.1	464	337	SHI c	18.22	2.75	400	376
SHE a	17.1	2.4	452	498	SHE c	16.69	2.28	347	487
BHI a	17.9	2.7	600	439	BHI c	17.04	2.45	519	488
BHE a	16.2	2.2	592	630	BHE c	15.79	2.06	469	627
SHI b	19.8	3.1	304	225	SHI d	18.69	2.80	266	251
SHE b	17.9	2.5	331	319	SHE d	17.40	2.39	244	299
BHI b	18.4	2.8	438	327	BHI d	17.46	2.49	382	363
BHE b	16.4	2.2	455	449	BHE d	16.01	2.16	352	437

Fertiliser application rate had the largest effect on N_2O emissions from fertiliser. INT and EXT scenarios applying high levels of fertiliser emitted 0.25 - 0.30 and 0.10 - 0.12 kg N_2O kg^{-1} CW more than INT and EXT scenarios applying low levels of fertiliser, respectively. This was caused by the increase in N loading from fertiliser increasing the amount of N susceptible to being lost directly as N_2O or indirectly as NH_3 or NO_3. Increasing fertiliser application rate increased net margin ha^{-1}, grass yield (t DM ha^{-1}), stocking rates and output ha^{-1}. First cut silage harvest date influenced N_2O emissions from manure management. Harvest date was shown to have more of an impact on EXT scenarios, where an average difference of 0.12 kg CO_2e kg^{-1} CW was seen between N_2O emissions arising from manure management for scenarios harvesting on 5 May and 28 June. The increase in N_2O emissions from late silage harvesting was due to an increase in slurry production during housing that led to greater NH_3 emissions and therefore, indirect N_2O emissions. The increase in slurry was caused by the reduction in silage dry matter digestibility (DMD) as silage harvest date extended. Net margin ha^{-1} decreased as harvest date extended due to the reduction in the DMD of silage with maturity and increase in concentrate feeding to maintain animal performance, therefore, increasing feed costs kg^{-1} CW. Increasing stocking rate increased carcass output ha^{-1} and revenue ha^{-1}. However, the rate of increase in carcass output ha^{-1} was sometimes lower than N_2O emissions, resulting in a reduction in emission efficiency. This can be seen when comparing INT and EXT scenarios (Table 1). Overall, BH EXT with high fertiliser application rate and early silage harvest date was the most sustainable system.

Conclusion

This study has shown that SH suckler beef systems emit more N_2O and total GHG emissions kg^{-1} CW than BH systems. The BH production systems were also more profitable and sustainable as they had higher ADG and output ha^{-1} than SH systems. By applying fertiliser under appropriate conditions and higher application rates, grass growth ha^{-1} will increase, supporting a higher stocking rate ha^{-1} and, thus, resulting in improved productivity and emission efficiency. Harvesting first cut silage early in the year will improve forage quality, therefore, reducing feed costs ha^{-1}, increasing profit ha^{-1} and improving emission efficiency. Overall, the outcome of this study demonstrates that by applying good farming management practices, sustainability can be improved with little to no negative effect of GHG emissions.

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Options for sustainable intensification of Irish grassland-based dairy systems: an assessment of the nitrogen balance

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Abstract

In Ireland, the agriculture sector has a strategy to dramatically increase milk production by 2025. But agricultural expansion has to be coupled with achieving national reductions in GHG emissions, nutrient loss to water and ammonia emissions. In order to develop grassland management strategies that are both environmentally friendly and economically sustainable, it is imperative that individual mitigation measures for N efficiency are evaluated for cost-effectiveness. A model was developed to evaluate a range of intensification scenarios. The model dynamically links the Moorepark Dairy System Model with a grass growth module and a number of N loss modules to simulate the effect of farm management on production, N losses and economic performance. The model includes the option to assess the effect of N-loss mitigating measures including the use of nitrification and urease inhibitors and low emission slurry application techniques. We applied the model to assess a number of intensification scenarios to increase milk production. Milk production could be increased by 44% using a range of management practices, resulting in an increase in farm net profit. However, this was accompanied by an increase in total N loss of 55%. Application of a suite of mitigation measures reduced N losses per kg milk production (but not per ha) to below baseline level.

Keywords: nitrogen losses, ammonia, nitrate, nitrous oxide

Introduction

In Ireland, the agriculture sector has a strategy to dramatically increase milk production by 2025. But agricultural expansion has to be coupled with achieving national reductions in GHG emissions, nutrient loss to water and ammonia emissions.

The quantity and form of N loss is highly dependent on farm management. Recent research has yielded increasing insight into the disaggregated N losses from different sources, i.e. urine and dung excretion in the field, fertiliser application and manure storage and on the effect of N loss mitigation strategies such as low emission slurry application and the application nitrification and urea inhibitors. In order to develop grassland management strategies that are both environmentally friendly and economically sustainable, it is imperative that individual mitigation measures for N efficiency are assessed on farm system level and evaluated for cost-effectiveness. To this end, we developed a model to simulate an Irish grass-based dairy farm, and the effects of farm management on N losses, production and economic performance. The model includes the option to assess the effect of using nitrification and urease inhibitors. We apply the model to assess the effect of different strategies to achieve the increased production goals of Food Harvest 2020 on N utilization, N loss pathways and economic performance at farm level.

Materials and methods

The model dynamically links the Moorepark Dairy System Model (Shalloo *et al.,* 2004) with a grass growth module and a number of N loss modules to simulate the effect of farm management on production, N losses and economic performance. The model includes the option to assess the effect of N-loss mitigating measures including the use of nitrification and urease inhibitors and low emission slurry application techniques. We applied the model to compare a number of intensification scenarios (Table 1) to increase milk production with a baseline scenario (B, typical Irish dairy farm). In scenario IG, we simulated increased milk production per ha through increased grass production as a result of optimised fertiliser application and sward management. In scenario IC, milk production was increased by increasing the concentrate feeding rate by 100%. Scenario IP was based on the research farm at Moorepark Teagasc Research station, aimed at increasing farm profit through an increase in grass utilised per hectare by dairy cows and higher genetic merit. For each of these scenarios we applied two mitigation options: 1) TS, reduced ammonia emission through 100% spring application of manure with trailing shoe and 2) INH, application of urease inhibitors to fertiliser and application of nitrification inhibitors (DCD) to animal feed.

Results and discussion

Milk production ranged from 8.3 t ha^{-1} for the baseline scenario to 12 t ha^{-1} for scenario IP, an increase in milk production of 44%. Milk production for scenario IG and IC was 11.5 and 9.6 ton ha^{-1} (Figure 1a). The increases in milk production per ha was the result of either an increased stocking rate (all scenarios), higher grassland utilisation (IP), higher grass production (IG and IP), increased concentrate feeding rates (IC), or increased milk production per cow (IP). The mitigation scenarios had little to no effect on farm productivity, as all potential effects on production (e.g. higher N utilisation from slurry with TS application) were offset by a reduction in fertiliser N application rates (data not shown).

The IG scenario increased the farm net profit from 301 € ha^{-1} (baseline) to 634 € ha^{-1}, as the extra costs associated with fertilisers and reseeding were easily off-set by an increase in income from milk. In contrast, increasing the concentrate feeding rate in the IC scenario resulted in a 67% reduction to 99 € ha^{-1} in farm net profit. The IP scenario dramatically increased farm net profit to 1,574 € ha^{-1}. The increased costs of applying slurry by trailing shoe (compared to splash plate) was partly offset by the decrease in artificial fertiliser requirement, and the net effect on farm net profit was very small. The application of inhibitors decreased farm net profit by on average 60 € ha^{-1}.

All the intensification scenarios resulted in increased N losses per ha compared to the baseline scenario (Figure 1b), ranging from 19 kg N ha^{-1} extra for scenario IC to 55 kg N ha^{-1} extra for scenario IP. The TS and INH mitigation scenarios resulted on average in 8 and 13% reduction of total N loss, respectively.

The increased losses in the intensification scenarios tended to be highest for ammonia. The TS mitigation strategy reduced ammonia emission by on average 11%, but the losses remained above the baseline scenario. Similarly, the intensification scenarios resulted in a strong increase in nitrate N loss, ranging from 14% for IC to 49 and 50% for IG and IP, respectively. The use of inhibitors resulted in a substantial reduction in nitrate leaching of 37% to below the baseline level. Nitrous oxide losses ranged from 5.8 kg

Table 1. Overview of model inputs for baseline scenario (representing a typical Irish dairy farm) and the different scenarios for increased milk production.

Scenario	Fertiliser N (kg ha^{-1})	Fertiliser P (kg ha^{-1})	Fertiliser K (kg ha^{-1})	Concentrate (kg cow^{-1})	Milk yield (l cow^{-1})
B: Baseline	160	5	13	834	5,102
IG: Increased grass production	250	19	22	834	5,102
IC: Increased concentrate	160	5	13	1,668	5,102
IP: Increased profit	250	20	18	392	5,600

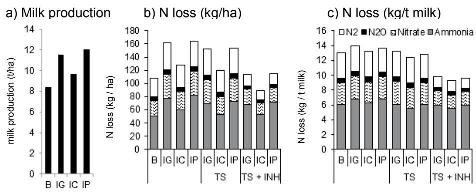

Figure 1. Results of simulated baseline (B) and intensification scenarios (IG, IC and IP) and the mitigation options (TS and combined TS + INH)

N ha^{-1} in the baseline to 7.4 kg N ha^{-1} in scenario IG and IP. TS and INH mitigation strategies resulted in a 2 and 27% decrease in N_2O losses on average, to below the baseline scenario level.

The milk N footprint (N loss in kg N t^{-1} milk produced) was higher for all intensification scenarios (Figure 1c). The TS mitigation resulted in a small reduction of N footprint to around the baseline level, whereas the use of inhibitors resulted in a significant decrease in milk footprint to below the baseline scenario for all intensification scenarios.

The soil N balance ranged from 47 (baseline) to 127 kg N ha^{-1} (IG + TS and INH). An increased soil N balance may be an indication of potential long term effects on either N uptake or N losses. However, this post must be interpreted with caution, as the soil N balance is calculated as the 'unaccounted' mass balance of N in the model.

Conclusions

The target increase in milk production of 50% to 60% (Food Harvest 2020 and Food Wise 2025, respectively) is at the upper limit of what can realistically be achieved without increasing the total area for dairy production. All the intensification scenarios resulted in increased N losses. The combined mitigation scenarios reduced the milk N footprint to at or below the baseline level for all N-loss pathways, whereas the N-loss per ha remained above baseline level for ammonia.

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Nitrogen flow on an organically managed beef farm in Hokkaido

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Abstract

The Yakumo experimental farm of Kitasato University has produced commercial beef under organic management, without the use of agricultural chemicals or imported feed, since 2005. Using a dataset obtained from 220 ha of grassland and 250 head of cattle over the five years from 2008 to 2012, we estimated nitrogen (N) flow. During 2011 and 2012, we measured grass production, cattle production, soil parameters and atmospheric deposition. To determine N fixation by clover, we compared grass + clover plots with grass-only plots. Averaged over the period, N components on the 220 ha of grassland comprised 1,952 tonne (t) soil N stock, 3.2 t N yr^{-1} in living livestock, 14.3 t N yr^{-1} uptake by grass growth (including 8.6 t yr^{-1} of N fixed by clover), 15.7 t N yr^{-1} applied in composted manure, 1.7 t N yr^{-1} in imported bedding material, 2.8 t N yr^{-1} in deposition, and 1.41 t N yr^{-1} in meat production. The N from composted manure equalled about 0.8% of the huge soil N stock; N in grass production equalled about 0.7%, of which clover fixation supplied 60%; N deposition was considerably important and N export by meat production was minor. These results show that on this organically managed farm, soil N stock increased gradually (by 8.6 t N yr^{-1} (220 $ha)^{-1}$ = 39 kg N ha^{-1} yr^{-1} = 0.44% of the soil N stock) and N export was small. Our results show that it is possible to balance N inputs with N outputs in a beef cattle enterprise without the need for feed or fertilisers import. LCA results were discussed with data of N flow.

Keywords: N fixation, composted manure, beef production, N deposition, N balance, LCA

Introduction

The food sufficiency ratio in Japan is only 38% of calories (MAFF, 2016), the lowest in the world. The annual nitrogen (N) balance on an agricultural land basis is currently +187 kg N ha^{-1}, and the phosphorus balance is +49 kg P ha^{-1} (OECD, 2013). These surplus nutrients can cause water pollution through NO_3-N leaching and air pollution through emissions of N_2O and ammonia. The accumulation of heavy metals from manure from imported feeds also poses a problem for Japanese soils. For a long time, Japanese beef cattle fed on imported feedstuffs have been famous for their well marbled meat. More recent consumer interest is in less fatty meat, which might lessen the need for imported feed.

Kitasato University manages a resource-recycling beef production enterprise on its Yakumo experimental farm (Yakumo Farm), where the grasslands have been managed entirely by 'organic' means since 2005 without the use of imported feed, inorganic fertilisers, or agricultural chemicals; only composted manure produced on the farm is applied, along with some imported bedding material such as wheat straw. 'Kitasato Yakumo Beef' is commercially produced on the farm and marketed in Tokyo as lean 'organic' meat. Although the farm practices organic farming, the objectives are to reduce the risk of environmental pollution and to deliver safe, reliable meat to the consumer, not to obtain organic products itself. This organic farming system is unique in Japan and because inputs into the farm are limited, it is easy to analyse nutrient flows.

A part of the objectives of the study were to estimate: (1) the N pool in the farm's soil, (2) N uptake by grass growth, including N fixed by clover, (3) wet and dry N deposition, (4) N exported in meat, (5) the amount of N applied in composted manure, and (6) to determine the total N balance of the enterprise.

Materials and methods

The Yakumo Farm is located in Yakumo-town, southern Hokkaido (42°25'N, 140°13'E, 145 m a.s.l.). The annual temperature averaged 8.1 °C and precipitation averaged 1,262 mm over 2002 - 2012. The 370 ha farm includes 220 ha of grassland in seven blocks. A 250 head herd of beef cattle (Japanese Shorthorn and Japanese Shorthorn × Salers cross) that graze in summer (May to October) and are housed in winter (November to April), producing about 60 carcasses annually. Nothing is imported onto the farm except for some bedding material, mostly wheat straw and bark. Only composted manure, produced on the farm, is applied to the grassland. The dominant pasture species are orchardgrass (*Dactylis glomerata* L.), Kentucky bluegrass (*Poa pratensis* L.) and white clover (*Trifolium repens* L.). The soil is classified as Low-humic Allophanic Andosols. The farm is isolated from other commercial farms and is surrounded by woods. Yakumo Farm was established in 1976 from former commercial dairy farms comprising grasslands and some cornfields. Limited amounts of inorganic fertilisers were applied between 1996 and 2004 - 20 kg N ha^{-1} yr^{-1}, 7 kg P ha^{-1} yr^{-1}, 26 kg K ha^{-1} yr^{-1}, 162 kg ha^{-1} yr^{-1} of magnesium lime, and 23 kg ha^{-1} yr^{-1} of fused phosphate, in addition to four tonne (t) ha^{-1} yr^{-1} of composted manure. Following the change to organic management in 2005, the soil chemical conditions between 2008 and 2012 were as follows: pH, 6.38 ± 0.36 (SD); available P (Bray No. 2), 43.04 ± 17.56 mg P (100 mg dry soil)$^{-1}$; exchangeable calcium, 382.47 ± 165.97 mg Ca (100 mg dry soil)$^{-1}$; exchangeable magnesium, 78.62 ± 36.64 mg t (100 mg dry soil)$^{-1}$; and exchangeable potassium, 33.61 ± 19.99 mg K (100 mg dry soil)$^{-1}$.

We measured N stocks and flows on the farm on the viewpoints of grass production; Nitrogen fixation, soil N stock, composted manure application, bedding materials, precipitation and deposits and meat production. The final annual nitrogen balance on the farm was calculated as follows:

- Inputs (t N yr^{-1}) = N fixation by clover + wet and dry deposition + bedding material
- Outputs (t N yr^{-1}) = meat production (+ estimated ammonia emissions)
- Balance = Inputs – Outputs

Results and discussion

Nitrogen flow on the farm

Averaged over 2008 to 2011 or 2012, the N components on the 220 ha of grassland comprised 1,952 t soil N stock (in 2011), 3.2 t N in living livestock, 14.3 t N uptake by grass growth (including 8.6 t of N fixed by clover), 15.7 t N applied in composted manure, 1.7 t N in imported bedding material, 2.8 t N in deposition and 1.41 t N in meat production. The N contributed by composted manure equaled about 0.8% of the huge soil N stock; N in grass production equaled about 0.7%, of which clover fixation supplied 60%; N deposition was not negligible and N export by meat production was minor. These results show that on the organically managed Yakumo Farm, soil N stock increased gradually (by 8.6 t N yr^{-1} = 39 kg N ha^{-1}), N export was relatively small and N fixation by clover is important for grass production. In great contrast, conventional commercial beef farms import a lot of feed and inorganic fertilisers (Jarvis, 2011).

On Yakumo Farm, the N balance was ideal from the viewpoint of environmental conservation because of the limited imports. The total N balance of the farm gives a slight annual surplus of 8.6 t N, which is about that fixed by clover, or 39 kg N ha^{-1}. The 14.3 t of N in grass includes 8.6 t N fixed by clover, meaning that the soil supplies 5.7 t N yr^{-1}, or 26 kg N ha^{-1}. This value is very common in this area.

Conclusion

The N balance of Yakumo Farm shows that the farm's organic management maintains a close to balanced flow of N on the farm. The soil N stock showed a gradual annual increase (8.59 t N yr^{-1} or 39 kg N ha^{-1}

equivalent to 0.44% of N stock). These results show that it is possible to balance N inputs with N outputs in a beef cattle enterprise without the need for feed or fertiliser imports.

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The Biodiversity Exploratories: a large-scale framework project for functional biodiversity research

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Abstract

The Biodiversity Exploratories (www.biodiversity-exploratories.de) are a broad-scale research project with 300 people involved addressing interactions between land-use intensity, biodiversity and ecosystem functioning in agricultural grasslands (and managed forests). The project started in 2006 and aims at gathering data for functional biodiversity research, for both basic and applied questions. In each of three study regions in Germany, 50 grasslands have been selected along a broad gradient in land-use intensity, ranging from unfertilised sheep pastures and single-cut meadows up to intensely fertilised three-cut grasslands or mown pastures. The Biodiversity Exploratories investigate, for example, relationships between land use and ecosystem functions to explore options as to how grassland management can promote high-level ecosystem services. We also show results of a sward disturbance and seed addition experiment, which successfully enriched plant diversity in almost all grasslands under study. The encountered seed and dispersal limitation is, on the one hand, a major obstacle for species conservation, as plant diversity does not automatically recover after a phase of highly intensive grassland management. On the other hand, a depleted species-pool is also of agricultural relevance, as in extensively used grasslands, the annual yield and other important ecosystem functions were shown to potentially benefit from more diverse plant communities.

Keywords: functional biodiversity research, permanent grasslands, nature conservation, ecosystem services, grassland management, grassland restoration

Introduction

Why is it important to study the effects of biodiversity on ecosystem functioning? Functional biodiversity research explores drivers of biodiversity changes and subsequent functional consequences for ecosystems and the goods and services they provide. Experimental evidence demonstrates that more diverse model ecosystems have higher levels of functioning than less diverse systems, e.g. increased biomass production at higher levels of plant diversity in experimental grasslands (Isbell *et al.*, 2011). However, we still do not know much about real-world effects of biodiversity on ecosystem functioning. Due to far-reaching changes in land use and environment, we additionally need to understand the effects of these major global drivers on the interactions between biodiversity, biogeochemical processes and ecosystem functioning (Fischer *et al.*, 2010). Finally, the translation of findings into practice has to be facilitated, for example, by restoring plant diversity in species-poor agricultural grasslands.

Materials and methods

The Biodiversity Exploratories (www.biodiversity-exploratories.de) were established in 2006 within three regions in Germany. The project comprises 300 study plots, with 50 plots in grasslands and 50 plots in forests in each region. Grassland plots are arranged along a gradient of land-use intensity, which can be seen as representative of large parts of Central Europe (Fischer *et al.*, 2010). Management ranges from extensively grazed, unfertilised pastures and single-cut meadows to highly fertilised three-cut meadows or mown pastures. All plots are on-farm and regularly managed. Along with the differences in management, the productivity of the sites varies strongly from 0.3 to 4.5 t DW per ha (peak standing crop in mid-May), as does plant species richness (12 to 71 vascular plant species on 4 × 4 m; Klaus *et al*., 2013). The high number of spatial replications and the 300 people from different research institutions involved make the Biodiversity Exploratories one of the largest research projects on ecosystem functioning worldwide. The three study regions differ in landscape, climatic, geological and topographical conditions, species pools and socio-economic settings. They reflect a gradient of rising altitude, increasing precipitation and slightly decreasing annual mean temperatures from north-eastern to south-western Germany. The regions are (1) the Schorfheide-Chorin in the north-east, a fairly flat post-glacial landscape; (2) the National Park Hainich and surroundings in Central Germany, a loess covered calcareous low mountain range; and (3) the Schwäbische Alb in the south-west, a slightly more elevated calcareous low mountain range with loamy soils.

In 2014, we established a full-factorial seed addition and sward disturbance experiment in four 7 × 7 m subplots in 73 grasslands across the three regions. For the disturbance treatment, the top 10 cm of the grassland sward were destroyed in October using rotovation tilling or a rotary harrow. The subsequent seed addition (reseeding) consisted of adding a highly diverse, region-specific seed mixture of plant species from the regional species pool. The mixtures were the same within but differed among the regions and contained 47 to 66 species including grasses, legumes and non-legume herbs. Seed addition was done twice, in November and the following March. Further details on the experimental set-up can be found in Klaus *et al*. (2017).

Results and discussion

Land use intensity is a major driver of ecosystem functioning in these grasslands and biodiversity loss is an important mechanism by which land use affects multifunctionality, the simultaneous provision of multiple ecosystem functions and services (Allan *et al*., 2015). Although the strength of the land-use effects on the 14 studied ecosystem services varied considerably among the three regions, supporting and especially cultural services suffered most from land-use driven biodiversity losses (Allan *et al*., 2015). The restoration of biodiversity in agricultural grasslands might therefore be able to offset some negative effects of intensification by promoting the delivery of a wider range of services. When experimentally altering plant diversity, seed addition had increased plant species richness already seven months after the treatments, but only in combination with sward disturbance. This short-term increase was significant for all regions with an average rise of 38% (+10 species per 4 m^2 plot) compared to the untreated control plot. Only in one region (Schorfheide-Chorin), was germination from the seed bank able to significantly increase plant diversity after disturbance, even without seed addition. However, germination from the seed bank had a much smaller effect on diversity than seed sowing and most of the species that recruited spontaneously were arable weeds (Klaus *et al*., 2017). During the second season after the experiment was established, the effect of the disturbance and seed addition treatment strengthened to increase in plant diversity by 55% (+15 species per 4 m^2 plot). During the next years, we will assess how this increase in plant diversity will affect ecosystem functioning, for example, nutrient retention and litter decomposition.

Conclusion

Large-scale research projects such as the Biodiversity Exploratories provide the potential to substantially advance our mechanistic understanding of drivers of ecosystem functioning and can provide knowledge about the importance of biodiversity for ecosystem processes and services. To increase plant diversity in grasslands, a combination of sward disturbance and high-diversity seed addition is most promising to overcome seed and dispersal limitation of grassland species and can therefore, be recommended for ecological restoration when other restoration measures such as hay transfer are not feasible. The established experiment will also enable us to analyse long-term effects of vegetation change on ecosystem processes and on the diversity of other taxa in real-world grasslands. In addition to protecting species-rich sites, nature conservation should also consider measures to actively enrich plant diversity of existing permanent grasslands e.g. by explicitly rewarding such measures in agri-environmental schemes and as greening measures.

Acknowledgements

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Magnitude, drivers and mitigation of nitrous oxide emissions from ruminant urine and dung patches

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Abstract

Over 40% of nitrous oxide (N_2O) emissions from pastoral grass-based agricultural systems are attributed to animal urine and dung nitrogen (N) deposited on pasture, range and paddock (PRP). With Irish agriculture dominated by these systems, it is essential to accurately account for these N_2O emissions and also elucidate their drivers and potential for mitigation. These emissions are currently reported using default IPCC emission factors (EFs). The objectives of this study were to: 1) estimate N_2O emissions and their associated EFs from ruminant urine and dung patches in grazed grasslands, 2) assess impact of environmental drivers on emissions and potential of using soil-specific manipulation of grazing timing as a N_2O mitigation tool, and 3) assess the efficacy of manipulation of minor ruminant urine constituents hippuric (HA) and benzoic acids (BA) on mitigation of N_2O from urine patches. Nitrous oxide emissions and associated EFs not only varied largely between type of excreta, soil type and season of application but also differed from the default EF value of 2%. Simulation of dietary manipulation to reduce N_2O emissions, through altering individual urine constituents (HA and BA), have previously delivered significant N_2O reductions in laboratory experiments, however, they appeared to have no effect *in situ*.

Keywords: nitrous oxide, emission factor, mitigation, cattle excreta, dung, urine

Introduction

Ruminant livestock is characterised by a low nitrogen (N) utilisation efficiency returning 70-95% of ingested N onto pasture as dung and urine (Oenema *et al.*, 2005). These excreta are a major source of emission of the greenhouse gas (GHG) nitrous oxide (N_2O). Emissions of N_2O arising from these returns comprise over 40% of the N_2O associated with animal production systems (Oenema *et al.*, 2005). Irish agriculture is dominated by pastoral-based ruminant livestock production which creates approximately 8.46 kt N_2O from urine and dung returned onto pasture, range and paddock (PRP) by grazing animals. Currently, these emissions are calculated using a default IPCC emission factor (EF) of 2%. However, literature suggests that there are large differences in N_2O emission factors associated with soil and environmental conditions, or the type of excreta (de Klein *et al.*, 2003). Therefore, there is a prerequisite to investigate emission factors specific to different climatic conditions, with Ireland a typical example of a temperate maritime climate. Additionally, drivers and potentials to mitigate losses arising from these specific conditions need to be assessed and evaluated. Some of the examples of N_2O mitigation are the use of soil-specific manipulation of grazing timing or dietary manipulations aiming at altering urine composition, leading to reduced N_2O emissions. This paper summarises two experiments and presents results from field trials quantifying N_2O emission factors from temperate pastures from varying soil types and over different seasons and the potential to mitigate losses through various interventions.

Materials and methods

In the first field trial, five replicates of urine and dung patches were applied to pasture in three seasons (spring, summer, autumn) on Irish pasture soil types (well-drained, moderately-drained, imperfectly-drained) at three sites (Table 1). A split plot experimental design was employed with site as the main plot factor, application season as the main split plot factor and excreta treatment as the split-split plot factor. Nitrous oxide measurements took place for 12 months following excreta application using a static chamber method. Ancillary measurements (temperature, rainfall, soil moisture deficit (SMD)) were collected at weather stations within 1 km from experimental sites. The effect of soil type, season and excreta type was assessed with analysis of variance.

In the second field trial, undertaken at the moderately drained site, ruminant composition was manipulated through incremental additions of hippuric acid (HA1 and HA2) and/or benzoic acid (BA) (Table 2). Urine was applied to pasture in a fully randomised block design with six replicates and N_2O was measured over two months using the static chamber method. The effect of urine composition on cumulative N_2O was determined with analysis of variance.

Results and discussion

In the first trial, application of cow excreta to grassland soil resulted in an immediate large increase in N_2O emissions, with peak losses higher than the control occurring within the first 60 days of application. However, in autumn on the poorly-drained soil, emissions from the urine treatments remained higher than the control for approximately 130 days, leading to greatest N_2O losses and highest EFs in this study (Figure 1a). Losses were associated with high rainfall and high soil moisture conditions, conducive to denitrification. The multiple regression analysis using weather data explained 72% of the variation and included cumulative rainfall for the five days prior to application, mean soil temperature in the seven days prior to application, and mean soil moisture deficit for the five days post-application. Application of urine universally produced significantly larger N_2O losses in comparison with dung (Figure 1a). The average N_2O emission factor was 0.31 and 1.18% for cattle dung and urine respectively, which were both considerably lower than the IPCC default value of 2%.

In the second trial, urine deposition increased cumulative N_2O emissions compared to the control. The short-term N_2O emission factors ranged from 0.9 - 1.3% (Figure1 b), substantially below the 2% IPCC default emission factor. However, there were no significant effects of urine manipulation on cumulative N_2O emissions. This could be due to a variety of reasons, such as leaching of HA/BA or high spatial variability. Moreover, previous studies reporting HA or BA mitigation effects were conducted in laboratory conditions on soil cores with no vegetation present. Mechanical disturbance of soil,

Table 1. Treatment application rates in the first field trial.

Soil	Urine N application rate (kg N ha^{-1})			Dung N application rate (kg N ha^{-1})		
	spring	summer	autumn	spring	summer	autumn
Well-drained	660	774	739	490	469	420
Mmoderately-drained	638	725	718	490	469	420
Imperfectly-drained	507	840	897	280	651	441

Table 2. Treatment application rates in the second field trial.

Treatment	Abbreviation	Urine N application rate (kg ha-1)	Hippuric acid (mM)	Benzoic acid (mM)
Urine	U	1,046	0	21
Urine and low hippuric acid	HA1	1,032	8	52
Urine and high hippuric acid	HA2	865	82	17
Urine and high benzoic acid	BA	1,073	24	96

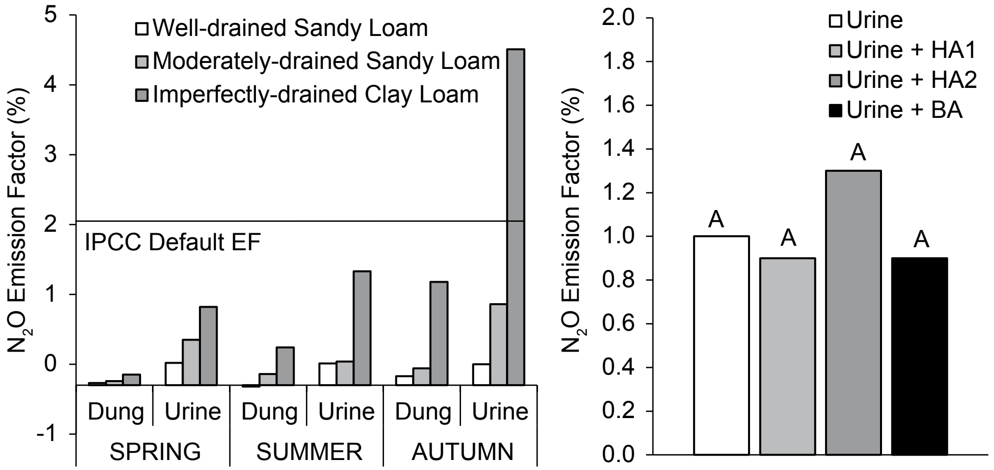

Figure 1. Direct nitrous oxide emission factors (a) for different excreta sources over three seasons and applied to three different soils measured over 12 months and (b) following minor urine constituents manipulation over two months.

such as sieving and drying, can alter microbial community size, structure and function and could have subsequently affected residence and metabolism of HA and BA in soil.

Conclusion

High variability of N_2O emissions with soil type and season presented here suggest that using a universal EF in national GHG inventories is inappropriate and application of country, or if possible, soil and season specific values, should be used. Presented results also support disaggregation of the EFs by excreta type. There is potential for a decision support tool to be developed to reduce N_2O emissions by modifying grazing management based on the weather and soil parameters such as rainfall and soil moisture. Regarding manipulation of ruminant urine constituents, although promising N_2O loss mitigation responses to increasing levels of benzoic and hippuric acid in urine were observed in laboratory studies, these acids were not effective at reducing N_2O *in situ*.

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Methane emissions and milk carbon footprint of dairy cows at grazing or fed with a concentrate diet

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Abstract

In order to compare methane emissions and carbon footprint of milk produced by dairy cows with different feeding strategies, a trial was carried out on two groups of 11 Holstein cows from May to July 2017. One group was grazing day and night with a target sward availability of 17 kg per cow. The other one received a diet composed of dried pellets mixed with straw, molasses and alfalfa hay. In the barn where all the cows had permanent access, an automatic concentrate supplier provided concentrates to complement the ration of both groups. Methane emissions were assessed by predictions based on the mid infra-red spectra of milk samples and by the Guardian® located in the automatic concentrate supplier. Furthermore, ruminal fluid was sampled monthly on five cows of each group to check the ruminal function (pH, redox potential, presence and mobility of protozoa). The aim of this study was to get an holistic overview of the effect of contrasted feeding practices on methane emissions, environmental impact, zootechnical and economical performances. Grazing decreased feeding costs and feeding environmental impacts while methane emissions per kg milk increased. This highlights the complexity of mitigation actions of GHG in the dairy sector.

Keywords: grazing, methane, dry ration, dairy cows, ruminal function

Introduction

Agriculture is usually considered responsible for 12% of the global production of greenhouse gases (GHG) (Tubiello *et al.*, 2014). Methane from ruminal fermentation contributes for 40% of the total agricultural emissions. Thus, mitigation of methane (CH_4) production could allow reducing livestock impact on climate change and may improve the public perception towards this sector. On the other hand, grasslands are well known as a carbon sink. Although grazing has several benefits e.g. for animal welfare, most Belgian farmers lack confidence in grazing because of the limited control over grass intake. Furthermore, a decrease in milk yield is usually observed with high amounts of grazed grass in cows' diets in comparison with the performance recorded with a controlled barn-fed diet. Lower percentages in fibres of dry rations could decrease CH_4 emissions. The aim of this trial is to assess in an holistic way, the effects of two feeding strategies – grazing (G) and dry diet (DR) – on milk yield, milk composition, CH_4 emissions, ruminal function, milk carbon footprint and feeding costs.

Materials and methods

The study was conducted at the CTA in Wallonia from May to July 2017. Twenty-two Holstein cows in early lactation were divided into two groups balanced regarding milk yield (MY), days in milk (DIM) and lactation number (LN). The group DR received a dry ration composed of 12.2 kg DM concentrates, 1.7 kg DM straw, 0.7 kg DM molasses and 36 kg DM alfafa while the group G grazed day and night. Both rations were completed by 3.5 kg of concentrate provided at the automatic concentrate supplier. The crude protein (CP) content in the concentrate was 20%. The DR chemical composition were 880 VEM kgDM^{-1} (Dutch unit for energy), 96 g DVE kg^{-1} DM (Dutch unit for protein available in intestine), 182 g CP kg^{-1} DM and 326 g NDF kg^{-1} DM. At the beginning of the trial, specifications of groups were for DR: 57 ± 41 DIM, 2.4 ± 4.4 LN and 35.7 ± 8.0 kg MY while for G group, DIM were 62 ± 42, LN

2.5 ± 1.8, MY 36.3 ± 7.7 kg. Grass growth was measured in a plot excluded from grazing where grass was mowed on a 10m-length band every week. The mowed grass was weighted and dried to calculate the grass density. Grass intake was calculated by subtracting the grass height when cows left the paddock from the grass height when they entered the paddock and multiplying it by the grass density (240 kg dry matter (DM) cm^{-1} ha^{-1}), by the surface of the paddock. This figure is then divided by the number of cows present on the paddock. Individual milk samples were analysed monthly for milk quality and for methane emissions prediction which were evaluated by milk spectra analysis following Vanlierde *et al.* (2016). Methane emissions during concentrate intake were measured by the Guardian® following the procedure described by Garnsworthy *et al.* (2012), allowing methane emissions to be measured on a daily basis. Ruminal fluid was obtained by oro-pharyngeal sampling and ruminal function was evaluated following the procedure described by Lessire *et al.* (2017). Feeding costs were calculated on current feed price basis. Environmental impact of feeding was estimated by calculating emission factors (kg-eq CO_2) of each feed component using the Feedprint® (Vellinga *et al.*, 2014) then by adding them in *pro rata* of their % in the ration.

Data were analysed by SAS 9.3. A proc mixed model was used with repeated measures (repeated days/ subject animal) statement and a covariance analysis type cs.

$$Y_{ij} = \mu + Gr_i + NL_j + date + date \times Gr_i + e_{ijk}$$

where μ = the overall mean with fixed effects being Gr_i = group effect (i = 1 to 2 for group 1 = dry diet to Group2 = grazing), date: day of sampling or measurement, NL: effect of lactation number (k = 1 to 3- 1 = primiparous, 2: 2d lactation and 3 = over the second lactation), date XGr_i: interaction group X date; $e_{ijk:}$ residual error.

Results

The weather conditions during the trial period were drier and hotter than the previous years, affecting the grass growth estimated at 27.2 kg DM d^{-1} ha^{-1} and 27.1 kg DM d^{-1} ha^{-1} in June and July, respectively. The grass intake of the G group was estimated at 15.1 kg DM grass per day over the grazing time. The mean grazed grass composition was 21 ± 6% DM, 216 ± 37 g CP kg^{-1} DM, 432 ± 26 g NDF kg DM^{-1}. The digestibility was on average 85 ± 2%, the energy value 1,018 ± 31 VEM g kg^{-1} DM, DVE 103 ± 7 g kg^{-1} DM. The daily concentrate intake was 3.3 kg per cow in DR and 3.4 kg in G group.

The DR group had a significantly higher milk yield and lower milk fat content (Table 1).

The CH_4 emission prediction per cow was similar in the two groups. Expressed by kg of milk, this was significantly lower in the DR group compared to the G group: 12.3 ± 0.5 vs 18.1 ± 0.5 respectively ($P <$ 0.001). This is coherent with the measurements obtained with the Guardian®.

Regarding ruminal function parameters, ruminal pH and redox potential were lower in DR than in G (5.94 ± 0.12 vs 6.58 ± 0.12, $P < 0.001$and 17.06 ± 4.35 sec vs 52.8 ± 4.13 sec, $P < 0.001$). Protozoa evaluation was graded at 2.11 ± 0.32 in DR vs 1.4 ± 0.31 in G (ns).

The daily feeding cost of the G group was lower than that of the DR group (1.98 vs 5.93 € / cow). The cost per kg of milk in G group was cut in half compared to DR group (0.08 vs 0.17 € / kg milk). The environmental impact of feeding was lower in grazing group compared with DR group whatever the used unit. The feed related emissions of the G group were 2.800 kg $eqCO_2.d^{-1}$ while they reached 15.020 kg $eqCO_2.d^{-1}$in the DR group. Reported per kg milk or kg ECM, they were still lower in the G group (107 g $eqCO_2$. kg^{-1} milk vs 415 g $eqCO_2$. kg^{-1} milk; 116 g $eqCO_2$ kg^{-1} ECM vs 481 g $eqCO_2$ kg^{-1} ECM, respectively).

Table 1. Comparison of milk yield and composition, methane emissions (g cow-1 d-1- g kg-1 milk) predicted from infrared spectrum between the groups.[1]

	Group 1 (dry diet)	Group 2 (grazing)	Statistical significance
Milk yield ($kg.cow^{-1}.d^{-1}$)	36.2 ± 1.2	26.2 ± 1.2	***
ECM (kg)	31.2 ± 0.9	24.0 ± 0.9	***
% fat	3.03 ± 0.10	3.52 ± 0.10	***
% protein	3.09 ± 0.05	2.98 ± 0.05	ns
Urea ($mg.l^{-1}$)	358 ± 20	376 ± 20	ns
CH_4 ($g.d^{-1}$)	434 ± 8	452 ± 8	ns
CH_4 ($g.kg\ milk^{-1}$)	12.3 ± 0.5	18.1 ± 0.5	***
CH_4 ECM ($g.kg\ ECM^{-1}$)	14.3 ± 0.9	19.8 ± 0.9	***

[1] Different superscripts show statistically different values. Values are LSMeans ± SE. ECM: energy corrected milk.

Conclusion

Feeding with grazed grass was beneficial in terms of feeding costs and feed related environmental impact while methane emissions per kg milk were higher than those of the DR group. This demonstrates the need to get an overview as complete as possible as some mitigation actions (e.g. grazing) could have contradictory impacts on the different GHG components emitted by the dairy sector.

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Grazing practices in three European countries: results of a survey in dairy farms

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Abstract

Grassland plays an important role in mitigation of greenhouse gas (GHG) emissions from the agricultural sector by sinking carbon (Soussana *et al.*, 2010). Thus, grazing is often essential for maintenance of grassland. Furthermore, grazing has demonstrated positive effects on animal welfare, production costs, landscape and biodiversity. However, grazing is decreasing in most European countries. For the project Life Dairyclim, a survey was undertaken in the three partner countries for a better understanding of grazing practices and of perceptions and expectations of dairy farmers. A questionnaire was distributed to dairy farms of south Belgium (BE), Luxembourg (LU) and Denmark (DK). Of 1,439 responses, 1,147 declared that lactating cows grazed (80%) but this result reflects different situations; 95% lactating cows were grazing in BE while this percentage dropped to 83% in LU and 37% in DK. This lower percentage of lactating cows seemed to be linked to larger farm surface, bigger herd size and increased milk yield. The opinion about benefits of grazing depended on the grazing practices. Grazing farmers were convinced of the beneficial effects of grazing on animal welfare (95.4%) and on landscape preservation (86.1%). Surprisingly, the positive effect on environment was mentioned in only 61.3% forms and even a negative impact was cited in 16.6%. Eighty six percent of surveyed farmers expected to continue grazing.

Keywords: grazing, grassland, grazing practices, environmental impact, climate change, mitigation

Introduction

Agriculture is considered to be responsible for 12% of the global production of greenhouse gases (GHG) (Tubiello *et al.*, 2014). The potential of grassland to store carbon provides an opportunity for the sector to mitigate GHG emissions (Soussana *et al.*, 2010) and grazing livestock may help in maintaining these ecosystems. Yet, grazing is decreasing in most European countries, probably because of the development of intensive farming systems and of automation. Furthermore, the mitigation potential of grassland is influenced by the type of grassland and its management (Gerber *et al.*, 2013). One of the objectives of the European project, Life Dairyclim is to highlight the importance of grasslands in dairy farming as potential carbon sink and to improve grazing practices. We surveyed the dairy sector of the three participating countries to get an overview of grazing practices and to assess the perceptions and expectations of the farmers about grazing. By analyzing the responses, we aimed to understand the reasons for the decrease of grazing and determine levers of action to encourage it.

Materials and methods

The questionnaire was written with the three partners in Luxembourg (LU), south Belgium (BE) and Denmark (DK), and consisted of 18 questions about the overall description of the dairy farm, its grazing practices and perceptions and expectations of farmers. The questionnaire was circulated by mail, during conferences and on the project website. The survey lasted from December 2015 to March 2016. A global analysis was performed on the compiled data and then differences between countries were highlighted. The statistical software SAS (SAS Institute, 2002) was used for descriptive procedures and analysis of the categorical variables. Chi-square test and Fisher- test were used to test equality of proportions.

Results and discussion

Of a total of 6,132 forms distributed to dairy farms in the three countries, 1,464 were completed, indicating a response rate of 23.9%. The most represented system was the conventional one (1,287 responses – 89%), while 136 organic farms were recorded (9.6%). Belgium and Denmark reached 9.2 and 11%, respectively. In Luxembourg, only three farms were included in the organic system (3%) but two other farms did not answer the question.

Thirty nine percent of farms specialised in milk production. Belgian farms had more diversified activities (28% milk, meat and crops $P < 0.05$). The size of Danish farms was larger than those from BE and LU in terms of ha and the number of cows (Figures 1, 2).

The level of milk production was also higher with nearly 50% of DK farms declaring an annual milk yield averaging 10 - 12,000 kg while only 2% BE and 4% LU reached that level. Eighty percent of farmers declared lactating cows grazing with contrasted situations: 95% lactating cows were grazing in BE while this percentage dropped to 83% in LU and 37% in DK. A set of questions addressed no-grazing farmers. In DK, the most frequently cited reasons for stopping were economic reasons (55% of responses), reduction in milk yield (MY) and difficult grazing management for 48%. DK farms clearly related grazing to a possible decrease in MY and consequently, a fall in income. The opinion about benefits of grazing depended on the grazing practices. Danish farmers were the most critical; for example, merely 47% of them considered that grazing lowered production costs while 73% in LU and 78% in BE agreed with this. Landscape preservation was cited as a benefit of grazing for 87% of DK farms.

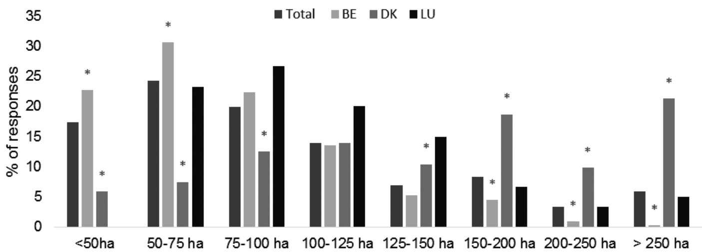

Figure 1. Surfaces of the dairy farms from each country and comparison with the compiled dataset. Statistical differences ($P < 0.05$) are identified by '*'. BE: Belgium. DK: Denmark. LU: Luxembourg.

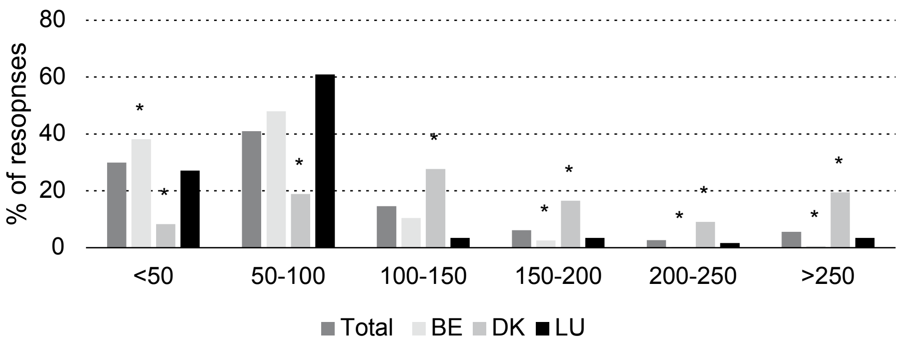

Figure 2. Number of dairy cows per farm from each country and comparison with the compiled dataset. Statistical differences ($P < 0.05$) are identified by '*'. BE: Belgium. DK: Denmark. LU: Luxembourg.

Farmers with grazing systems were very convinced about the beneficial effects of grazing on animal welfare (95.4%) and on landscape preservation (86.1%). Surprisingly, grazing was considered positive toward environment by only 61.3% and considered to have a negative environmental effect by 16.6%. This latter high percentage is due to the Danish farmers who estimated that grazing had a negative impact (42.2%). Eighty-six percent of surveyed farmers expected to continue with grazing systems.

Conclusion

Analysis of survey's results demonstrated that a decline in grazing is mainly observed in intensive dairy farms. Reasons provided for stopping, which mainly related to economic and difficult management, confirm this hypothesis. As already demonstrated by Kristensen *et al.* (2010); opinions about grazing depend on grazing practices. Grazing is negatively perceived by farmers without grazing systems. Nevertheless, through its potential for carbon storage, preservation of grassland contributes to the mitigation of GHG emissions of the agricultural sector. Educational effort is necessary to raise the awareness among farmers about the environmental impact of grazing and to highlight their role in mitigation of GHG emissions. This is crucial for their involvement in EU greening policies.

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Energy expenditure and methane emissions of grazing dairy cows at two levels of pre-grazing herbage biomass

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Abstract

We quantified the effect of biomass on energy expenditure (EE), methane emissions (CH_4) and FPCM of grazing dairy cows. The experiment was carried out in November 2015. Treatments were two contrasting levels of pre-grazing biomass (LOW vs HIGH) at a daily herbage allowance (DHA) of 30 kg DM (above 5 cm). Eight multiparous Holstein cows were used in a 2×2 Latin Square design. DMI was estimated using Cr_2O_3 and digestibility by faecal index (N and ADF). Grazing time was determined by observation between milking (9 hours). EE was estimated from heart rate and O_2 pulse, CH_4 was determined using the SF_6 tracer technique. Pre-grazing herbage height and biomass above 5 cm differed significantly (48 vs 37 cm, $P = 0.0374$; 1,859 *vs* 1,447 kg DM ha^{-1}, $P = 0.05$). However, DMI (18.3 kg d^{-1}; $P = 0.5101$), grazing time (324 min; $P = 0.6522$), and EE (725.8 kJ kg MW^{-1}, $P = 0.7986$) did not differ among treatments. Therefore, FPCM and CH_4 yield were similar (20.6 kg d^{-1}, $P = 0.7527$; 21 g kg DM^{-1}, $P = 0.7115$, respectively). In the current study, biomass in LOW was higher than intended which would explain the lack of difference in daily intake and EE at grazing.

Keywords: dairy, biomass, intake, energy expenditure, methane emissions

Introduction

In low input grazing systems, the efficiency of production highly depends on the use of pastures. National research has shown that an increase in concentrate supply without an efficient use of pastures does not contribute to reduce Carbon Footprint (CF) (Lizarralde *et al.*, 2014). Grazing animals have an extra daily maintenance requirement due to the demand of energy for the physical activities of forage intake and walking, which would explain the lower productivity of grazing systems compared with confined animals (Di Marco y Aello, 2001). In low biomass pastures, the extra energy expenditure per activity could reach 25 to 30% due to the cost of grazing, which should result in an increase in methane emissions per liter of milk produced and CF. For predominantly pasture-based dairy systems, it is important to adjust management practices that lead to an increase in milk production and therefore, a reduction in CF. This study aimed to quantify the effect of biomass at the same herbage allowance on intake, energy expenditure, daily methane emission and fat and protein corrected milk yield of grazing dairy cows.

Materials and methods

The experiment was carried out in Uruguay (32°22'S, 54°26'W) during spring 2015 on a pasture comprising *Dactylis glomerata* and *Medicago sativa*. Two contrasting pre-grazing biomass (LOW and HIGH) in a 2 × 2 Latin Square with eight Holstein dairy cows (21 ± 0.5 kg milk; 190 ± 12.4 DIM; 537 ± 13 kg BW). Experimental plots were cut 35 (HIGH) and 15 days (LOW) before the beginning of the experiment and offered at a Daily Herbage Allowance (DHA) of 30 kg DM cow^{-1}, measured above 5 cm·. OMI was determined using Cr_2O_3 to estimate faecal OM output, and Nf and ADFf contents in faeces to estimate OMd (Comeron and Peyraud, 1993). Grazing time and biting rate were determined between milking (Astigarraga *et al.*, 2002). CH_4 emission was measured using the SF_6 tracer technique reported by Johnson and Johnson (1994) adapted by Gere and Gratton (2010). Energy expenditure (as heat production: HP), was estimated using the HR- O_2 pulse method (Brosh *et al.*, 1998). The HP measured by this method was compared with the HP value predicted based on the DMI and the energy retained by the animal (ER).

Results and discussion

Considering that pasture allowance is the main factor affecting pasture intake, the effect of biomass was analysed at the same DHA. The variations between treatments were within the expected, although these differences were smaller than intended. This was mainly due to the climatic variations registered during November, throughout the experimental period. Considering this, it is worth mentioning that it was possible to differentiate both treatments in quantity of biomass without affecting its quality.

The different biomass between treatments had no effect on daily intake. This could be explained by the high DHA per cow according to what was reported by Peyraud *et al.* (1996), Tharmaraj *et al.* (2003), Pérez-Prieto and Delagarde (2013), who show that intake reaches a maximum when pasture allowance is from 25 to 30 kg DM a^{-1} d^{-1}, determined at 5 cm or 60 kg MS a^{-1} d^{-1} at ground level (similar values to those of pasture allowance at ground level expressed in this work). Grazing time did not differ between treatment, however, the biting frequency was higher in LOW which could indicate a compensation mechanism for lower bite weight in this treatment. Enteric methane emission values did not differ between treatments and CH_4 yield (*Ym*) was 7% on average. HP values recorded for this experiment are

Table 1. Pre-grazing pasture characterisation for HIGH and LOW herbage biomass.

	HIGH	LOW	SEM	*P*
Herbage mass above 5 cm (kg DM ha^{-1})	1,859	1,447	160.1	0.0500
Pre-grazing height (cm)†	48	37	3.9	0.0374
Post-grazing height (cm)†	27	19	1.21	0.0015
Chemical composition # (g kg DM^{-1})				
OM (g kg^{-1})	909	905	5.2	0.5524
CP	137	142	2.4	0.2635
aNDFmo	588	566	9.8	0.2661
ADFmo	321	294	3.3	0.2507
GE (MJ kg DM^{-1})	16.7	16.2	0.85	0.6514

† measured as extended sheet; # above 5 cm; OM: organic matter; CP: crude protein; aNDFmo: neutral detergent fiber without sodium sulfite and with heat stable amylase; ADFmo: Acid detergent fiber; GE: gross energy.

Table 2. Daily intake, milk production, methane emission and energy expenditure of cows grazing at HIGH and LOW swards.

	HIGH	LOW	SEM	*P*
Herbage OM digestibility (g kg OM^{-1})	737	743	5.5	0.2811
Herbage OM intake (kg a^{-1} d^{-1})	17.0	16.4	0.63	0.5102
FPCM (kg a^{-1} d^{-1})	20.6	20.7	0.47	0.7527
Grazing time (min)	321	327	13.7	0.6392
Biting rate (N° min^{-1})	36	42	9.5	0.0296
Methane emission (g a^{-1} d^{-1})	374	353	34.9	0.6852
Heat production (kJ kg MW^{-1})				
Measured HP (kJ kg MW^{-1})	733.6	718.0	58.57	0.7986
Predicted HP (kJ kg MW^{-1})	1,134.5	1,045.0	81.54	0.3090

MW = $BW^{0.75}$

slightly low for cows producing 20.6 kg PCM on average. The estimation of HP from the energy partition analysis would seem to support the assumption that the predicted HP value is closer to the expected value than the HP measured by the O_2P-HR method. Finally, if there was an effect of the biomass on the feeding behaviour (frequency of bites), this did not manifest itself in a different EE due to activity between treatments.

Conclusion

Pre-grazing biomass evaluated in this experiment did not affect forage intake, milk production or methane emissions from grazing dairy cows associated with an estimated DHA above 5 cm close to the forage offer that allows the maximum voluntary consumption in grazing for animals of these characteristics to be expressed.

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Modelling the impact of new EFs on grassland fertiliser GHG emissions estimates from Irish dairy systems

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Abstract

The default Intergovernmental Panel on Climate Change (IPCC) emissions methodologies use the same nitrous oxide (N_2O) emissions factors (EFs) for all nitrogen fertilisers but significant differences have been shown between grassland emissions from calcium ammonium nitrate (CAN) and urea. Using dairy farm management and production data from the 2015 Teagasc National Farm Survey, fertiliser-based grassland emissions were estimated using the default methodology and with novel disaggregated N_2O EFs, including an interaction with soil group, testing different drainage assumptions. Emissions estimates with the new EFs were significantly lower than the default approach if agriculturally limited use soils were assumed to be well or moderately well-draining, but were greater than the default approach when farms with this soil group were assumed to have impeded drainage, or when averaged EFs with no soil type interaction were used for all farms. These results have significant implications for national agricultural emissions and emissions methodologies.

Keywords: greenhouse gas emissions, emission factors, fertiliser, nitrous oxide, urea

Introduction

Agriculture is under pressure to reduce its associated greenhouse gas (GHG) emissions. This is an especially prominent consideration in Irish dairy production, as ruminant systems are of relatively high emissions intensity, and the industry produces a significant component of Ireland's national emissions. It is not feasible to directly measure emissions on each farm, and so instead, estimates are generated by applying emissions factors (EFs) to activities that result in GHG emissions. Default EFs are provided under IPCC guidelines ('tier 1'), but nationally specific (tier 2) or more detailed (tier 3) approaches can be used where there is supporting evidence. In the Irish National Inventory Report (NIR), GHG emissions resulting from synthetic fertiliser applications are currently estimated using a tier 1 methodology (Duffy *et al*., 2017). However, recent research has demonstrated that emissions can vary significantly between different fertilisers and depend on soil drainage (Harty *et al*., 2016). This paper explores some of the impacts of using these disaggregated EFs for Irish dairy farms in 2015.

Materials and methods

Grassland area, soil group, fertiliser applications, milk output, stocking rates and economic gross outputs were obtained for all 319 dairy farms from the 2015 Teagasc National Farm Survey (NFS, part of the EU Farm Accountancy Data Network, FADN). Emissions resulting from synthetic fertiliser applications to grassland were estimated using the EFs in Table 1 following either the default coefficients as used in the 2017 Irish NIR, or new CAN and urea disaggregated EFs under three different assumptions. The first approach used the same disaggregated CAN and urea EFs for all farms, regardless of soil type, using average values across all soil drainage classes as reported in Harty *et al.* (2016), listed in Table 1 below as the CAN and Urea EFs with no soil interaction (referred to as the 'average' new approach in results section below). The other two methods used separate fertiliser EFs depending on soil drainage class, also as reported in Harty *et al.* (2016), shown as moderately/well drained or impeded drainage EFs in Table 1 below. The only soil data associated with each farm was an agricultural usage class based on Gardiner and Radford (1980), with soil group 1 defined as wide or moderately wide agricultural use, soil group 2 somewhat limited and limited use, and group 3 very or extremely limited use. As these soil groups may not directly correspond with soil drainage class, two different assumptions were tested: an 'optimistic' approach where farms in soil groups 1 or 2 both used the moderately/well drained EFs and soil group 3 used the impeded drainage EFs, and a 'conservative' approach where only soil group 1 used the moderately/well drained EFs (and groups 2 and 3 used the impeded drainage EFs). N_2O emissions resulting from leaching and urea CO_2 emissions used default EFs as in the NIR.

Emissions were expressed per unit of milk output (standardised to 4% fat and 3.3% protein fat and protein corrected milk, FPCM) and as a total for all farms represented. Fertiliser emissions were assigned to milk production alone based on the proportion of livestock units in each farm enterprise and an economic allocation based on the relative value of milk and meat outputs from the dairy enterprise of each farm. Sixteen farms did not have milk composition data and so were excluded from per FPCM analyses. Farm emissions (with no economic re-allocation) for all 319 farms were multiplied by their NFS weighting factor (describing how many farms each survey farm represents nationally) then summed to give total emissions.

Table 1. Emissions factors used for quantification of grassland emissions from synthetic fertilisers.

Emission modelled	Emission factor				Reference
	No soil interaction	Moderately/ well drained	Impeded drainage		
Direct N_2O – NIR	1			% N	IPCC default
Direct N_2O – New EFs, CAN	1.49	0.87	2.74	% CAN N	(Harty *et al.*, 2016)
Direct N_2O – New EFs, Urea	0.25	0.18	0.40	% Urea N	(Harty *et al.*, 2016)
Atmospheric deposition N_2O NIR	0.023			% N	(Duffy *et al.*, 2017)
Atmospheric deposition N_2O, CAN	0.014			% CAN N	(Harty *et al.*, 2016)
Atmospheric deposition N_2O, Urea	0.137			% Urea N	(Harty *et al.*, 2016)
Leaching N_2O	0.075			% N	(Duffy *et al.*, 2017)
Urea CO_2	20			% Urea	IPCC default

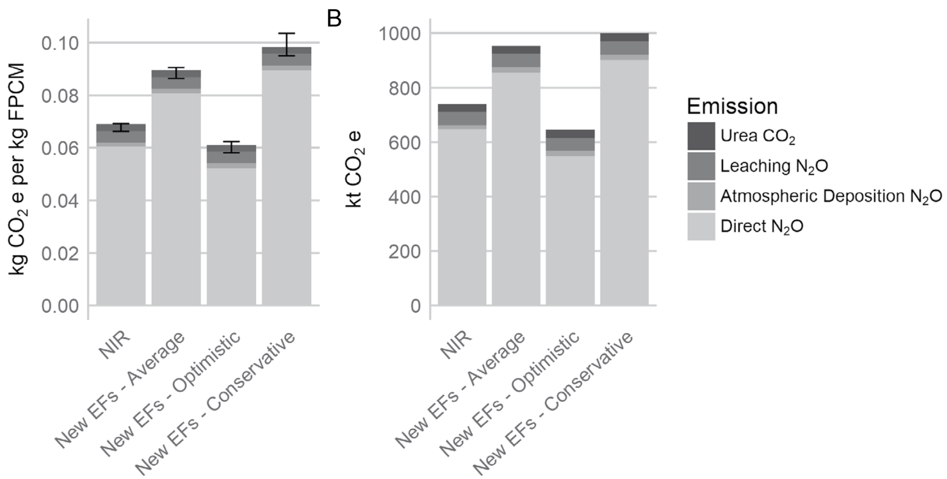

Figure 1. Emissions from grassland synthetic fertiliser on Irish dairy farms in the 2015 Teagasc National Farm Survey using default emissions factors (EFs) from the 2017 Irish National Inventory Report (NIR), and from recent research taking the average for all soil types, or following optimistic or conservative assumptions on soil drainage status. Illustrated as a) per kg fat and protein corrected milk (FPCM) sold and b) total emissions for all farms represented. Error-bars represent BCa 95% confidence intervals.

All analyses were performed in R. A boot-strapping approach was used with 10,000 re-samples to generate Bias-Corrected and accelerated (BCa) 95% confidence intervals for weighted mean emissions per kg FPCM using the package 'boot' (Canty and Ripley, 2017). Differences between groups were tested using a weighted permutation test, followed by post-hoc pairwise weighted permutation tests with false discovery rate (FDR) correction using the package 'coin' (Hothorn *et al.*, 2017).

Results and discussion

As shown in Figure 1a, the emission factors used and assumptions made in modelling emissions had a significant impact of fertiliser emissions per kg FPCM ($P < 0.001$), and all methods differed from each other ($P < 0.01$ in all pairwise comparisons). New estimates for grassland fertiliser emissions under the average (0.089 kg CO_2e per kg FPCM) and conservative (0.098) approaches were significantly higher than the default method (0.069), due to the dominance of use and higher EFs of CAN. Under the optimistic approach, treating soil group 2 as moderate/well drained, grassland fertiliser emissions were estimated at 0.061 kg CO_2e per kg FPCM, significantly lower than the NIR, as both urea and CAN EFs were lower.

At national level (Figure 1b), total dairy grassland fertiliser emissions could potentially be 243 (average) or 260 (conservative) kt CO_2e above, or 95 kt below (optimistic) the default approach (740 kt). This large difference highlights the importance of sufficient activity data (here soil drainage) to support our improved mechanistic understanding of emissions processes. On-going work providing a geospatial reference for all farms in the Teagasc NFS could be used to develop these estimates further and use updated soil drainage databases. The results also imply a general move to increase use of urea instead of CAN could result in significant GHG emissions reductions, but protected urea formulations must be used to avoid pollution swapping from N_2O to ammonia (NH_3) emissions (Harty *et al.*, 2016).

Conclusion

Refined emissions factors were demonstrated to have a significant impact on estimates of grassland fertiliser based emissions. The new EFs could result in significant increases or decreases to the carbon footprint of milk, depending on soil drainage assumptions. This result highlights the need to incorporate wider data and geospatial modelling in order to generate more detailed emissions estimates. It also reveals the potential for significant emissions reductions to be made based on fertiliser choices.

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Silvopastoral agroforestry - an option to support sustainable grassland intensification

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Abstract

Intensive and semi-intensive temperate grassland systems often revolve around landscapes which have poor ecosystem services delivery. This work demonstrates that the introduction of wide spaced trees in silvopastoral agroforestry systems can make these grassland landscapes more sustainable, deliver a wide range of ecosystem services and align with a sustainable grassland intensification strategy. Silvopasture is shown to extend the grazing season to help higher grass utilisation and give resilience to grazing during extreme rainfall, while increasing short-term carbon storage and long term carbon sequestration. Favourable economic predictions, farmer surveys and policy inclusion also indicate that governments consider silvopastoralism as a realistic future land-use option.

Keywords: soil trafficability, water infiltration, carbon sequestration

Introduction

Agroforestry can be defined as the integration of agriculture and forestry on the same land unit. The interactions between the two components can be managed to produce a stream of production and environmental benefits over time. In silvopasture, a form of agroforestry, stock graze pasture between widely spaced trees. As such, agroforestry can be considered as a means of introducing trees into the farmed landscape while delivering objectives for sustainable grassland intensification. Agroforestry systems have been shown to be a welfare-friendly livestock system which delivers a wide range of ecosystem services (McAdam, 2000) and economic predictions have been favourable (McAdam, Thomas and Willis, 1999). To accelerate the pathway to a carbon neutral livestock system, (DAERA, 2017) recommended that farmers consider the benefits of establishing an agroforestry system on a proportion of their land to suit individual farm locations and catchments to add resilience to their grazing system in wet weather and allow earlier and later seasonal grazing. This paper reports the supporting evidence for this. In Northern Ireland, current levels of grassland utilisation are low (in the order of 5 t DM ha^{-1} yr^{-1}; DAERA, 2017) in beef systems and most grassland systems are net carbon sources. Given the uncertain seasonal rainfall profile, grassland utilisation can be seriously impaired by soil trafficability. Sustainable grassland intensification could be considerably facilitated by increasing the length of the grazing season through improved soil trafficability. Given predicted climate change for the region, the establishment of trees on pasture can reduce the flooding risk by significantly increasing the rate at which water can enter the soil, thus decreasing the flow of water into rivers and streams as well as creating drier grazing pastures for livestock.

Materials and methods

A long-term silvopastoral agroforestry site was established in Northern Ireland at Loughgall, Co. Armagh in 1989 (Sibbald *et al.,* 2001) to compare three land use types: (1) a silvopastoral system with ash trees (*Fraxinus excelsior L.*) planted at 400 stems ha^{-1}, (2) planted woodland with ash trees (2,500 ha^{-1}), and (3) permanent grassland. Soils at Loughgall are Brown Earth on Red Limestone Till with a soil pH range7.0 - 8.3, and clay content between 30 and 45%. There were three replicates of each treatment in a randomised block design, plots were approx. 1 ha each and individually fenced. The trial has been consistently managed and documented since planting with some intensive periods of measurement. The trial was a unique resource to assess the long term impact of silvopastoral systems on a range of ecosystem services. Soil carbon storage was investigated by soil sampling to 20 cm and analysing carbon content by soil fraction size (Fornara *et al.*, 2017). To estimate total carbon content in the tree component of the system, eight trees were completely excavated, soil washed off the stumps, the whole tree separated into leaves, twigs, small branches, large branches, trunk and roots (Olave *et al.*, 2016) and carbon content assessed. Soil moisture content was measured weekly from 1 August 2016 until May 2017 (mean of 10 values per plot over three replicate plots per treatment) and soil resistance to penetration (a measure of infiltration potential) measured through the soil profile (to approx. 80 cm) using a penetrologger weekly from September to November 2017.

Results and discussion

Carbon

26 years after the conversion of permanent grassland to either silvopastoral or woodland systems, while tree planting on permanent grassland may not contribute to greater soil C stocks it may, in the long-term, increase the C pool of more stable (recalcitrant) soil micro-aggregate and silt and clay fractions, which could be more resilient to environmental change (Fornara *et al.,* 2017). The mean carbon content of each tree was estimated at 336 kg and total C per unit area (at a tree density of 230 stems ha^{-1}) as 77.38 t ha^{-1} (Olave *et al.,* 2016). Over the life of the crop this was an accumulation rate of 3.68 tC ha^{-1} yr^{-1}. Given that accumulation rates of C in permanent grassland are in the order of 1 t ha^{-1} yr^{-1} and the nature of the carbon sequestered in the silvopasture, agroforestry has the potential to deliver a carbon neutral livestock system.

Soil trafficability

If a soil moisture content of 40% is taken as a notional limit for soil poaching to occur, between August 2016 and May 2017, the soil moisture content was below 40% for 17 weeks more in the agroforestry than the grassland (Figure 1).

This represents a potentially substantial increase in grazing season length. As part of a rotational grazing strategy, agroforestry paddocks could be saved for grazing at the beginning or end of the grazing season and thus, greatly increase grass utilisation.

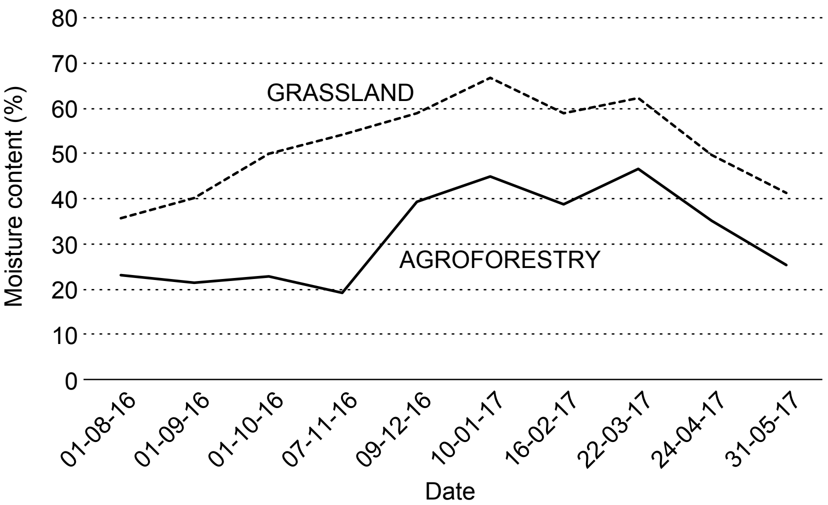

Figure 1. Soil moisture from August 2016 to May 2017 from grassland and agroforestry in a long term (26 y) grazing experiment at Loughgall, Co. Armagh ($P < 0.05$ ese 3.506).

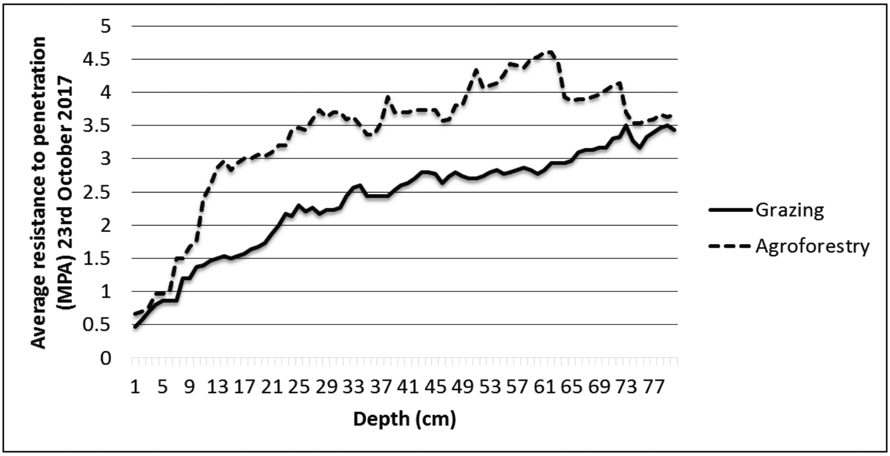

Figure 2. The average resistance to soil penetration (from Sept - Nov 2017) from grassland and agroforestry in a long term (26 y) grazing experiment at Loughgall ($P < 0.001$, ese 0.24).

Soil infiltration

The resistance to soil penetration (and hence infiltration) was greater in the agroforestry than the grassland to 76 cm depth (Figure 2). Hence, agroforestry has created a soil profile under grassland which will be much more resilient to potential flooding and predicted climate change and greatly increase the sustainability of grazed pasture.

Policy uptake

Economic predictions (McAdam *et al.,* 1999) and farmer surveys of agroforestry have been favourable but it is when agroforestry is accepted for state support that on-farm planting is likely to increase. In 2015, agroforestry was included as an option in forestry measures in Ireland and in 2017 as an option in the DAERA Environmental Farming Scheme in Northern Ireland. In the latter, the stipulated planting and management specification was based on the research findings from the trial reported above. Uptake has been encouraging and these farmers will hopefully encourage other applicants. In conclusion, silvopastoralism can reduce soil moisture, increase soil trafficability and thus, significantly extend the grazing season to improve grass utilisation and sustainability.

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A climate change mitigation strategy for the grasslands of the Falkland Islands

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Abstract

Small oceanic islands are particularly vulnerable to climate change given their isolation, biodiversity and self- reliance. Climate change predictions for the Falkland Islands (12,200 km^2 52°S, population 3,200) are for a 1.3 - 2.2 °C increase in temperature over the next 80 years. This could result in an unfavourable precipitation-evapotranspiration balance and given the dry (400 - 800 mm precipitation *per annum*), windy climate and shallow soil cover, contribute to the instability of the extensively grazed grasslands, increase the risk of soil erosion and increase loss of soil carbon. Agriculture is confined to extensive sheep farming in large enclosures. Sheep numbers have been traditionally high but the building of a certified abattoir in 2005 created the opportunity to reduce numbers and associated GHG emissions. Recently, the development of pastures with improved grasses and legumes, coupled with rotational grazing, has received much greater priority. Now and in the future, soil and pasture management practices will play a key role in ecosystem services delivery and climate change mitigation in the islands. We propose that the Falkland Islands are an exemplar of climate change risk assessment and potential adoption into a government policy which is underpinned by the best scientific evidence available to mitigate impacts across a range of land use scenarios.

Keywords: *Cortaderia pilosa, Empetrum rubrum,* farm subdivision

Introduction

Geographical background

The Falkland Islands are an archipelago of 782 islands situated in the South Atlantic Ocean between latitudes 51°S and 53°S and longitudes 57°W and 62°W. They cover an area of c. 12,200 km^2 and are approximately 500 km from mainland South America. The climate is cool/temperate/oceanic, mean January and July temperatures are 9.4 °C, and 2.2 °C, and ground frosts can occur throughout the year. Rainfall is low (mean annual precipitation at Stanley of 640 mm), particularly in spring, and is unevenly distributed across the islands (Jones, Harpham and Lister 2013; McAdam, 1985). This, combined with strong spring winds, reduces pasture growth early in the season (McAdam, 1985, 1986). A typical Falkland soil comprises a shallow (usually no deeper than 30 cm), peaty horizon overlying a compact, poorly drained, silty clay subsoil. Mineral soils occur in areas wherever the underlying geology is exposed, particularly on mountain tops and in eroded and coastal areas. They have a pH in the range 4.1 to 5.0 and are deficient in calcium and phosphate. The main vegetation types are acid grasslands dominated by *Cortaderia pilosa* (Gramineae) and dwarf shrub heathland dominated by *Empetrum rubrum* (Ericaceae) (Summers and McAdam, 1993; McAdam, 2013). They have been little altered over the vegetation history of the islands. There is no native tree cover. Production of native pastures is low, typically in the range 1.-2.5 tDM ha^{-1} for *Cortaderia* grasslands while grasslands in valleys and around the coasts can produce up to 5t DM ha^{-1} (Summers and McAdam, 1993).

History of grassland use

Sheep (for wool production) has been the mainstay of the Island's economy since around 1865. Sheep numbers increased up to a maximum of 800,000 in the early 1900s. This population was probably too large and overgrazing of the better pastures may have led to the reduction in numbers of sheep after the turn of the century. Stock numbers declined to about 600,000 by 1930 and remained relatively constant (at a mean stocking density of approximately 1 sheep per 2 ha) until early in the 1980s when a programme of farm sub-division was introduced (Summers and McAdam, 1993). The burning of some pastures in spring to remove the fund of standing dead herbage had been widely practiced for many years. However, given the risk of accidental spread and peat burning the practice is no longer recommended. Some reseeding has been carried out using introduced European forage species (Davies and Riley, 1992; Kerr, 2003) and extensive forage and fodder variety trials are ongoing. Most of the grassland is extensively grazed throughout the year without serious impact as much of the material is indigestible. The performance of Falkland Islands' agriculture had not improved to any appreciable extent from the turn of the 19th century up until the radical structural change brought about by sub-division. In the first ten years after subdivision, sheep numbers increased by approximately 20% (Summers *et al.*, 1993). This rate of increase slowed down over the next ten years and by 2000 numbers were starting to decline. This was mainly caused by a destocking of many of the outlying islands and the construction of a certified abattoir which made meat production an option and an alternative to complete reliance on wool. Between 2004 and 2006, farming went through unprecedented change when farmers critically evaluated market options and most started to retain less sheep and cull at an earlier age. This resulted in a decline in overall stock numbers. Total sheep on farms was 482,031 in May 2015, down from approximately 650,000 at subdivision (DoA, 2015). Given the low human and high ruminant populations of the Falklands, it is inevitable that agriculture will be the main contributor to greenhouse gas emissions (Figure 1) and the impact of the reduction in livestock numbers as a result of the abattoir and other grassland practices on national GHG emission totals is significant.

Climate change predictions and impact of climate change

The last century has seen a 0.5 °C increase in annual mean temperature for Stanley, East Falkland (Lister and Jones 2014). Regional Climate Models predict a large increase in the rate of change, with a 1.8 (± 0.34 S.D) °C rise in the mean annual maximum temperature predicted by 2080 (Jones *et al.*, 2013). In contrast, little or no change is predicted for the daily temperature range or annual precipitation, although increases in temperature will inevitably lead to a changed distribution pattern of rainfall and increased storminess. The Falkland Islands Government have developed a keen interest in how climate change might impact the Islands' species, habitats and the ecosystems services they provide and are updating their Biodiversity Strategy accordingly. They wish to explore useful adaptation and mitigation strategies based on scientific evidence, particularly from an EU funded project to determine the impact of climate change predictions on terrestrial ecosystems (Upson *et al.*, 2017). Within this project a preliminary soil type and depth distribution map was produced. This quantified soil carbon stocks in the Falklands as 778 t C ha^{-1} and highlighted that, given the unfavourable potential evapotranspiration/rainfall balance, many of these soils are particularly vulnerable to cultivation (resulting in increased topsoil aeration and accelerated decomposition of organic topsoils) and (controlled) burning. The Department of Agriculture has produced guidelines on reseeding based on erosion risk reduction and climate change mitigation. These include seed selection and strict cultivation guidelines which align with best available scientific assessments of soil risk. In general, many threats to soils can be addressed through correct management of soil carbon and so the establishment of national guidelines on soil conservation can be seen as an important advancement in addressing potential climate change impacts. The Islands already invest heavily in renewable energy technologies, nationally over 50% of energy is generated from wind and all renewable resources (wind, sun, rainfall) are mapped for incorporation into business plans for individual settlements to select best possible options. We propose that the Falkland Islands are an exemplar of climate change risk assessment and open to adopting a government policy which is underpinned by the best scientific evidence available to mitigate impacts across a range of scenarios.

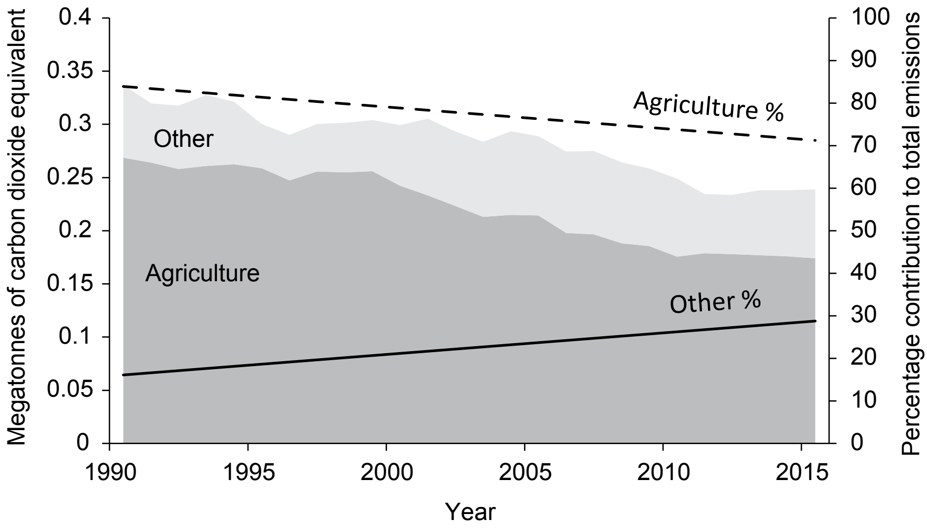

Figure 1. Greenhouse Gas Emissions Inventory 1990 - 2015 for the Falkland Islands. The 'Other' category includes waste management, transport, residential, land use change, energy supply and business.

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What is the role of nutrient management in grassland to achieve and sustain good water quality?

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Abstract

Optimum soil fertility for macro and micro-nutrients provides recognised benefits for achieving high levels of sustainable grass production, which, combined with efficient utilisation, can deliver both production and economic gains for farmers. Both national soil sampling databases and high resolution sampling in case-study catchments participating in the Irish Agricultural Catchments Programme (ACP), indicate that achieving and maintaining optimum levels of and available soil phosphorus (P), (measured as Morgan's P) i.e. between 5 and 8 mg l^{-1}, critically limits the risk of P loss to surfaces waters. This supports current regulatory measures to restrict P application to high/legacy P soils (> 8 mg l^{-1} Morgan's). Hence, over time, optimising P management should limit losses to water and avoid wasteful applications of an expensive finite resource. Although samples recording excessive P levels have declined both in national and ACP grassland soils, the mean decline towards sub-optimal P levels in a grassland dominated catchment from 6.8 mg l^{-1} in 2009 to 5.5mg l^{-1} in 2017 highlights the shortcomings in nutrient management practice on Irish farms. We explore the impact of changing farm practices in P utilisation on achieving sustainable intensification, in the context of optimum soil P, on ACP dairy farms.

Keywords: nutrient management, soil phosphorus, phosphorus balances, water quality

Introduction

Increasing evidence shows that optimising soil fertility through specific nutrient management practices (NMP) on farms can increase farm production and help to enhance profits (Buckley and Carney, 2013). Worldwide, effective nutrient management is recognised as a pivotal measure in reducing nutrient loss, in particular N and P, from field to water (Sharpley, 2016). In Ireland, since 2006, NMP's are core measures implemented as part of the commitment to the European Unions (EU) Nitrates Directive, to achieve and maintain good to high water quality. Given that P is considered to be a large contributor to algal growth in fresh water systems (Correll, 1998) the objective of NMP's are to reduce legacy (high) soil P by limiting P at the farm and field scale according to crop, animal and soil nutrient build up requirements. Since 2010, as part of the requirements to monitor the effectiveness of the nitrates directive, the ACP was established. Within six varying catchments of hydrology, land use and farming intensities are monitored at a high spatial resolution (< 2 ha) for soil nutrients specifically focused on P, while the nutrient load leaving is monitored continually at sub-hourly intervals at the outlet of each water shed (Wall *et al.,* 2011). Given the contact that these farmers have with the integrated advisory/research aspect of the ACP, the aim of this study is to understand if NMP's are having an effect on soil P change in intensively farmed grassland catchments. The objectives were to (1) examine the trends in soil P between 2009 and 2017 in two grassland catchments and (2) evaluate farm-gate P and soil P change from a representative intensive dairy farm within each catchment between 2013 and 2017.

Materials and methods

In 2009/2010, 2013 and 2014 soils were sampled at 10cm depth, with at least 20 cores randomly sampled in < 2 ha areas from two Irish catchments; (1) grassland Farm A which is mostly well-drained (7.5 km^2) and located in west Cork, and (2) grassland Farm B which is mostly poorly-drained (11.5 km^2) and located in Wexford. The 20 soil cores of each sample area were bulked, dried at 40 °C, passed through a 2mm sieve and analysed for Morgan's P, where results are commonly referred to as soil test P (STP). Data were categorised by soil P indices (Index 1 to 4) as determined in the GAP regulations. Descriptive statistics were used on the data and the P trends were reported as catchment area-weighted means in each P index. In addition, from two represented intensive dairy farms in each catchment farm-gate imports (inorganic fertilizer, feed and livestock) and exports (milk, livestock and crops) were recorded for 3 years between the two sampling periods of 2013 and 2017. Farm P balances were calculated as the balance of sum farm-gate imports minus the sum of farm-gate outputs. Based on Murphy *et al.* (2015) approach to account for the potential P build-up requirement allowance up to the optimum index 3 levels, the soil P balance was calculated as farm-gate P balance minus the standard P build-up requirements of the 2013 index 1 and 2 soils.

Results and discussion

Since the baseline year, the proportion areas with excessive STP levels (i.e. P index 4) declined by 12 and 3% respectively in both the grassland A and B catchments. This is a positive trend in reducing the diffuse source risk from legacy P to water from these catchments. However, there is a decline in mean STP levels in both catchments from 6.8 to 5.5 mg l^{-1} in grassland Farm A and 4.65 to 3.14 mg l^{-1} in grassland Farm B. After the 2nd soil nutrient census in grassland A, the indications were that NMP practices were influencing the convergence of soil P fertility towards the optimum levels (Murphy *et al.*, 2015). However, following the 2017 soil census the proportional area of index 3 soils declined by 16%, resulting in up to 60% of grassland A sub-optimal in STP levels. For grassland B, the proportion areas with sub-optimal soils (i.e. P index 1 and 2) continued to decline from 74% in 2009 to 89% in 2017. These catchment scale trends are reflective of national soil samples also reporting declines in soils with legacy P levels but with increases in national soil samples with sub-optimal STP levels (Plunkett and Wall, 2016).

From each catchment on farm nutrient use between the 2nd and 3rd soil, sampling dates are shown in Table 1 for two spring calving dairy farmers availing of the nitrates derogation exemption stocking levels (i.e. between 170 to 250 kg organic N ha^{-1}). In 2013, the STP breakdown for Farm A was 31% at index 1, 23% at index 2, 21% at index 3 and 25% in index 4. Because the average soil P balance was -10.1 kg ha^{-1} y^{-1}, this indicated that insufficient P was available in the grassland system of farm A for build-up

Table 1. Farm level inputs, exports and balances from 2014 to 2016 for two grassland dairy farms (Farm A and B) in two different catchments.

Year	Farm A			Farm B		
	2014	2015	2016	2014	2015	2016
Imports kg P ha^{-1}						
Inorganic fertiliser	3.91	0.82	6.36	7.49	8.15	16.63
Stock	0.00	0.81	1.22	0	0.10	0.10
Bulk feed	0	0	0			
Concentrates	4.89	4.57	5.83	6.00	6.93	7.34
Total imports	8.80	6.19	13.41	13.58	15.18	23.97
Exports kg P ha^{-1}						
Milk	5.79	6.05	6.89	8.41	9.64	9.21
Stock	4.04	2.98	5.07	2.89	3.24	4.25
Crops	0	0	0	0	0	0
Total exports	9.83	9.03	11.96	11.30	12.88	13.46
Balance (kg P ha^{-1})	-1.97	-5.45	2.78	2.28	2.30	10.51
P build up (kg P ha^{-1})	8.47	8.47	8.47	18.13	18.13	18.13
Soil P balance (kg P ha^{-1})	-10.44	-13.91	-5.68	-16.04	-15.84	-7.62

requirement on index 1 and 2 soils of this farm. The outcome in 2017 was that no area of the farm had STP levels at index 4, but 69% of the area was sub-optimal in STP and 31% at index 3. Although the average farm-gate P balance for grassland Farm B was slightly higher (4.97 kg ha^{-1} y^{-1}) than for Farm A, given that in 2013 the STP levels on this farm were much lower (i.e. 98% of the area was at index 1 and 2% at index 2); it is not surprising that by 2017 the entire farmed area was at index 1 for STP, given that the annual soil P balances remained in deficit. Expanding this analysis to represent other grass-based farm enterprises between soil sampling periods can help identify nutrient management issues and ensure best use of NMP to deliver sustainable grass growth for expanding Irish dairy farms.

Conclusion

Mining of legacy STP soils (i.e. index 4) is best practice for Irish grassland farmers for sustainable production that ensure that losses are minimised. However, over the study period of the ACP, it is evident from examining the trends in STP levels and P balances at farm and catchment scale that distribution of nutrients to sub-optimum soils is a continuing issue. This will become a barrier to sustaining increased outputs for many of these farms. Additional analysis of farm-gate and field nutrient balances across multiple farms and years will provide valuable information to what the main factors are in STP change and the impact these have in achieving sustainable grassland systems.

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Seasonal effects of drought on plant and microbial phosphorus concentration

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Abstract

Drought events are predicted to increase in frequency and magnitude in the next century, especially during the summer. Drought can affect phosphorus (P) uptake by plants and its availability, which is partially linked to microbial activity. A precipitation manipulation experiment was established on two permanent meadows in the Jura mountains to explore the seasonal responses of plant and microbial P to drought. The two meadows were characterised by similar vegetation but soils had different P availabilities. Drought stress was simulated during 8 weeks, either at the beginning of the growing season (Early) or later in summer (Late). Plots subjected to drought were compared to well-watered plots. Soil P, microbial P and plant P were analysed at the end of the two studied growing cycles. Plant P strongly decreased with drought stress. The effects of the Late drought were, however, stronger than those of the Early drought (significant season × drought interaction). Microbial P was impaired both by the drought treatment and the season. Despite important differences between the two soils, the experiment showed relatively similar responses to drought regarding plant and microbial P.

Keywords: soil moisture, plant-microbe interactions, climate change, microbial P

Introduction

Phosphorus is a key element in plant nutrition, which is mainly present in organic molecules such as nucleic acids, phospholipids and phosphoproteins (Schachtman *et al.*, 1998). The inorganic P dissolved in soil solution represents the available fraction for uptake by plants and microorganisms. The bioavailability of P is influenced by many factors, such as P sources, soil moisture and temperature (Sun *et al.*, 2017; Dijkstra *et al.*, 2015). During summer, soil water content usually decreases due to lower rainfall and high evapotranspiration. Beyond the reduced growth rate, related to lower CO_2 assimilation rate, water shortage also leads to changes in nutrient turnover. In particular, phosphorus cycling can be potentially affected by lower desorption (Belnap, 2011) and less diffusion (Lambers *et al.*, 2008), as well as by reduced plant uptake.

Soil microorganisms play an important role in nutrient cycling as they influence mineralization-immobilization and flux rates. Drought especially, impacts microbial and enzymatic activities (Steinweg *et al.*, 2012). As soil moisture diminishes, mineralization and immobilization rates weaken. Soil microorganism activity and plant nutrient uptake are closely related to each other, by competitive and/or symbiotic relationships.

In this experiment, we focused on the P turnover of two grasslands submitted to drought simulations. In particular, we examined the seasonal influence of drought stress on plant and microbial P. We addressed the following hypotheses: (1) water shortage leads to lower microbial and plant P and (2) – due to a stronger reduction in soil moisture – drought occurring in mid-summer (late drought) has more detrimental effects on P concentrations than a stress occurring at the beginning of the growing season (early drought).

Materials and methods

The drought simulation experiment was conducted in 2016 on two permanent meadows located in the Swiss Jura mountains at 930 and 540 m a.s.l. respectively for site 1 and 2. The vegetation in the two meadows was similar but the soils were not, especially regarding P availability: site 1 was P-rich, whereas site 2 was rather P-poor. Cutting occurred at 8-week intervals. Drought was simulated under rain shelters during two periods: either during the 8 weeks corresponding to the peak of the grass growth (*Early drought*) or during the following 8 weeks (*Late drought*). Drought plots received 30% of the 30-year precipitation average during the period of stress (i.e. Early or Late), whereas control plots were watered 100%. During the other periods, all plots were watered according to the average rainfall. Forage samples were taken during each harvest. P concentration was determined from dry ash, using an inductively coupled plasma optical emission spectrophotometer. Soil samples were taken just after the harvests and analysed regarding soil and microbial P concentration, using 3 g of fresh soil extracted with 40 ml of 0.5 M NaHCO3. The P concentrations were analysed by colorimetry using a spectrophotometer at 890 nm. Microbial biomass P was estimated as the difference between the amounts of P after and before fumigation, using an extractability factor of 0.4 (Brookes *et al.*, 1982). Statistical analysis was run by means of an ANOVA. The effects of 'site', 'time' and 'drought' (all fixed factors) and their interactions were tested in a nested randomized block design, the blocks being nested in the site.

Results and discussion

Soil extractable P showed great differences between the two sites. The concentrations at site 1 were about six times higher than at site 2 (Table 1). The season (time) and the drought treatment also influenced the available P (Table 2). Moreover, there was a strong interaction between site and time: important differences were observed between the two seasons at site 1, contrarily to site 2 where the P values were more constant over time.

Plant P was influenced by the site: P concentrations at site 1 were higher than at site 2 (on average 3.0 and 2.4 $g{\cdot}kg^{-1}$ DM, respectively; Table 1). Regardless of the site, the drought treatment induced a decrease in the plant P concentrations, which was more pronounced during the late time period (interaction time × drought; Table 2). Indeed, the decrease of plant P in the plots submitted to the late drought reached about 20%. In contrast, during the early drought, the difference to the control plots was small (– 6%).

Table 1. Mean (± s.e.) concentrations of phosphorus (n = 3) measured as soil extractable P ($mg{\cdot}kg^{-1}$), plant P ($g\ kg^{-1}$ DM) and microbial P ($mg{\cdot}kg^{-1}$ soil). Early drought occurred in the first eight weeks of the growing season (spring); Late drought occurred in the following eight weeks (summer).

Site	Time (season)	Drought treatment	Soil P (P-Olsen)	Plant P	Microbial P
Site 1 (P-rich)	Early	Control	64.1 (3.5)	3.1 (0.1)	55.2 (7.3)
		Drought	56.7 (2.9)	2.9 (0.0)	53.1 (9.6)
	Late	Control	40.2 (2.6)	3.5 (0.2)	31.6 (5.7)
		Drought	32.5 (2.1)	2.7 (0.1)	19.7 (5.7)
Site 2 (P-poor)	Early	Control	10.0 (1.0)	2.6 (0.2)	39.9 (2.1)
		Drought	8.3 (0.9)	2.5 (0.1)	26.1 (2.1)
	Late	Control	10.6 (1.3)	2.4 (0.2)	22.3 (1.3)
		Drought	7.3 (1.2)	2.0 (0.2)	13.6 (1.9)

Similar to the other tested parameters, microbial P was strongly site-dependent (Table 1). The season (time) had a strong influence on this parameter. Between the two timings (Early and Late), the microbial P declined on average by 50%. The influence of drought was important, but less than the season. In contrast to plant P, we did not observe an interaction between the season and the drought treatment, indicating no significant difference between the Late and Early drought (Table 2).

Table 2. Effects of the site, the time (season) and the drought treatment on the extractable P in the soil, the plant P and the microbial P. ANOVA *P* values are in bold when $P < 0.05$.[1]

	Soil P (P-Olsen)	Plant P	Microbial P
Site (S)	**< 0.001**	**0.001**	**0.012**
Time (T)	**< 0.001**	0.166	**< 0.001**
Drought (D)	**0.002**	**0.002**	**0.037**
T × D	0.720	**0.048**	0.760
S × T	**< 0.001**	**0.029**	0.109
S × D	0.066	0.173	0.597

[1] The interaction between site, time and drought was never significant and does not appear in the Table.

Conclusion

This experiment showed that drought lowered plant and microbial P. Furthermore, water shortage had more detrimental effects on plant P during Late drought than during Early drought. In a further step, special emphasis will be placed on the relationships between soil, plant and microbes in order to get a better understanding of the direct and indirect effects of soil moisture on plant P.

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Modelled consequences of climate change on fodder production in selected milk-exporting countries

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Abstract

The French dairy professional organisation, CNIEL, currently finances a study named Climalait with an international focus exploring the possible evolution of the climatic conditions in areas active on the world dairy market. This prospective study is based on the WorldClim data from the CNRM (RCP 8.5) and the LGP (Length Growing Period) proposed by the FAO. Several agricultural and climatic indicators were calculated for these areas, both on past periods (1950 - 2000) and for the future (2041 - 2060). The evolution of the LGP is estimated by a statistical model based on WorldClim data. Evolutions of the various indicators and of the LGP put areas with similar potential climatic futures regarding forage production to the fore. Some of these regions will gain real competitive assets.

Keywords: climate change, fodders, milk production, WorldClim data, Length Growing Period

Introduction

Climate change already impacts fodder systems of dairy farms (Noury *et al*., 2013) in France. Farmers noticed that they could turn out to grass sooner but that summer droughts were longer. Sometimes local difficulties emerge to achieve fodder stocks, irrigation being hence necessary to secure the forage balance of the farm. The French dairy chain represented by its professional organisation, CNIEL, financed a study on several axes. One of these studies investigates ways to adapt production systems to climate change as they may be proposed by farmers themselves in 30 zones distributed on the domestic territory. The second axis explores climatic conditions of fodder production in other milk producing countries as well as in a few French study areas from the first axis. Milk producing countries targeted in this study are those now acting as main exporters on the world market, or with the potential to do it in the near future (FAO *et al*., 2014): North America (various western or north-eastern areas such as Great Lakes, Saint Laurent and Texas), Rio de la Plata basin (Argentina, South Brazil, Paraguay, Uruguay), Oceania (south-eastern Australia, New Zealand) and Europe (several areas in France, Germany, Scandinavia, Poland, Ukraine, Belarus and Russia). Only results for European countries are presented here.

Materials and methods

Using statistical data of territorial cow distribution (Robinson *et al*., 2014), 61 areas were identified in 17 countries. In this study, RCP 8.5 was the climatic data used proposed by the WorldClim organisation (Fick and Hijmans, 2017), issued by the CNRM's climate simulator. The 10' resolution (one point every 18.5 km – 550,000 points) on the 1950 - 2000 (historical data) and 2041 - 2060 periods of time were selected. Variables are all period averages. It deals with 12 monthly values of minimal temperature, maximal temperature, precipitations (but not PET) and 19 indicators based on those 36 variables. LGP data available on the FAO site were used in order to estimate one of the possible impacts of climate change on fodder cultures. Length of growing period (LGP) is defined (FAO, 1996) as the year period when average temperatures are higher than or equal to 5 °C and precipitations plus moisture stored in the soil exceed half the potential evapotranspiration (P > 0.5 PET).

As achieved by Phelan *et al.* (2016) on the GSL (Grazing Season Length), a statistical model of LGP estimation was built on the basis of historical data from WorldClim base. This model was then applied on climatic data between 2041 and 2060. The difference between LGP estimated for the future and LGP estimated for the past with this model (Figure 1) is used as a synthetic indicator for evolution of climate conditions as experienced by grass.

In order to consolidate this major indicator, five others were calculated: the four season-evolution of the P-PET water balance, and the date foreseen for possible grass turnout (grass turnout = day when the sum of daily average temperatures since 1 February reaches a total of 300 °C) Sooner turnout to grass corresponding to LGP increase may mean a true extension of the possible period of grass use. Monthly PET were estimated from the temperature (Allen *et al.*, 1998), as the average of PET value obtained by the Thornthwaite formula and the one obtained by the Hargreaves formula: this solution was validated after comparisons to Penmann-Monteith PET available on French sites. Water balance evolution (P-PET) gives us information on the evolution of water intake conditions of summer fodder plants such as maize. Site classification was achieved using Principal Component Analysis and cluster analysis.

Results and discussion

WorldClim data analysis showed strong correlations among variables. Indeed, a multiple linear regression type LASSO (Least Absolute Shrinkage and Selection Operator) - very restrictive on variables' selection (Tibshirani, 1996) - was used. For the Northern hemisphere, the following data are part of the model: March maximal temperatures, February and October precipitations, precipitations of the driest quarter, temperature and precipitations seasonal distributions. In Europe (34 sites among 61 observed), the classification per evolution similarity brings out five classes (Figure 2). The A class countries (i.e. Russian areas) are characterised by a high raising LGP with possible earlier grass turnout. Autumn growth may be more sustained than summer growth because it appears that the summer water balance declines, which is also not favourable to maize crops without irrigation. For the C class countries (i.e. Poland, Belarus, Ukraine), the situation appears to be very profitable above all in the Western parts, with a possible extension of growth period (LGP) and a better water balance (despite a strong PET increase), which should be good for maize. There is already a precipitation pattern with summer maximum in those areas. The findings for the D class (Germany, south Scandinavia) is similar to A class as far as climate evolutions are concerned but represents a particular type due to less continental features (i.e. more precipitations and less temperature gaps). There are three sub-classes in E class (i.e. French areas). The first one corresponds to western Brittany with few temperature evolutions but a declining summer water balance. The second one deals with mountain zones (Jura and Massif Central) where growth periods may increase, particularly with earlier spring but a worse water situation in late spring and summer. Situations seem to be harder for

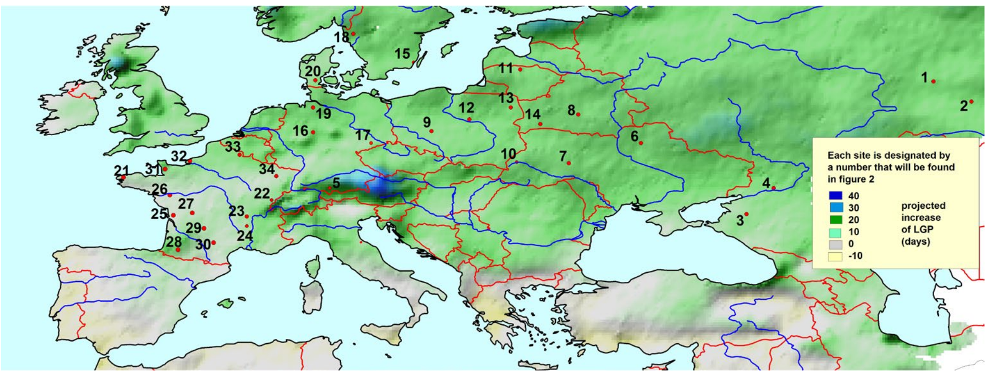
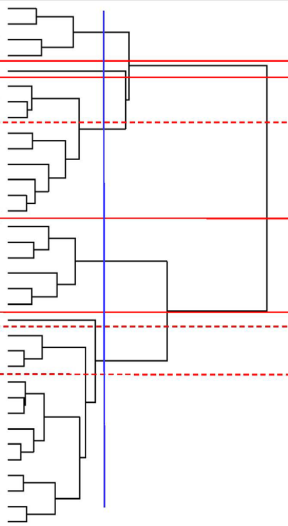


Figure 1. Projected increase in length of growing period (LGP) (number of days in period 2041 - 2060 - number of days in period 1950 - 2000).

south western sites in the third sub-class due to low raising LGP and decreasing water balances. However, it appears slightly better north of Seine. Finally, the situation in Bavaria appears quite peculiar (B class) with four indicators clearly evolving positively both for grass and maize crops. WorldClim data allow trends to be outlined on a rather thin geographical scale but not to study inter-annual climatic variability, one of the most sensitive aspects of the effects of climate changes on agriculture and livestock particularly.

Conclusion

According to RCP 8.5 and the CNRM climatic model, large lowlands of central Europe, from Rhine to Dniepr basin, seem to benefit from climate change with better prospects for grass and silage maize cultivation and growth. As a result, a synergy exists between milk production development dynamics and climate evolution. With summer water balance getting worse, evolution seems to be less favourable in western and south-western France.



Cluster analysis for 34 sites in Europe, based on evolutions between past and future of LGP and seasonal temperatures, precipitations and PET.		estimated LGP 2041-2060 - estimated LGP 1950-2000 (Days)	Sooner turnout to grass (days)	Future (2041-2060) Spring water balance - Past (1950-2000) Spring water balance (mm)	Future (2041-2060) Summer water balance - Past (1950-2000) Summer water balance (mm)	class
1	RUS Tatarstan	**17**	15	-21	-30	A
2	RUS Bachkirie	**14**	13	-25	-16	A
3	RUS Krasnodarsky Kray	**10**	15	2	-41	A
4	RUS oblast de Rostov	**13**	14	-14	-33	A
5	DEU Bavière	**18**	21	23	10	B
6	UKR Nijyn	**18**	16	2	-29	C
7	UKR Khmelnitsky	**19**	18	13	-6	C
8	BLR Minsk	**18**	16	9	-11	C
9	POL Poznan	**14**	19	25	6	C
10	UKR Lviv	**19**	23	25	5	C
11	LTU Siauliai	**17**	17	15	5	C
12	POL Mazovie	**15**	12	22	13	C
13	POL Poldachie	**16**	17	14	5	C
14	BLR Brest	**17**	17	12	2	C
15	SWE Kalmar	**14**	22	6	10	D
16	DEU Nord Rhénanie	**16**	18	29	8	D
17	DEU Saxe	**15**	23	21	3	D
18	SWE Götaland	**18**	15	12	9	D
19	DEU Basse Saxe	**10**	18	26	8	D
20	DNK Sud	**16**	19	21	3	D
21	FRA Léon	**4**	5	2	-19	E
22	FRA Doubs	**22**	22	17	-6	E
23	FRA Monts du Lyonnais	**10**	16	-4	-17	E
24	FRA Haut Vivarais	**11**	20	-12	-15	E
25	FRA Saintonge	**6**	6	-3	-27	E
26	FRA Mauges	**3**	7	-5	-23	E
27	FRA Confolentais	**5**	8	-5	-27	E
28	FRA Béarn	**8**	7	5	-21	E
29	FRA Périgord	**5**	7	-2	-25	E
30	FRA Tarn	**4**	6	-8	-23	E
31	FRA Bocage cotentin	**7**	7	10	-12	E
32	FRA Pays de Caux	**10**	9	11	-10	E
33	FRA Thiérache	**11**	12	14	-6	E
34	FRA Plateau Lorrain	**14**	14	13	-5	E

Figure 2. Evolution of the LGP and three other complementary indicators by class (sites evolving in the same way).

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Earthworms and grassland productivity: impact of the New Zealand flatworm and slurry

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Abstract

Earthworms are the major component of the soil fauna in European temperate grassland. Their feeding and burrowing activities recycle nutrients, aerate and drain the soil: ultimately, improving soil fertility and grass yield. In Northern Ireland, concerns have been raised about the impact of New Zealand flatworm (*Arthurdendyus triangulatus*) predation and the effects of continual livestock slurry applications on earthworm populations. In a manipulative field experiment, *A. triangulatus* density of 0.8 m^{-2} reduced overall earthworm biomass by 20% but large anecic species of earthworm suffered a reduction in biomass of c. 74%. A reduction of this magnitude could reduce ryegrass above-ground herbage production by 6-7%. Application of cattle slurry, on the other hand, largely benefitted earthworms, with epigeic species such as *Lumbricus rubellus* responding most positively.

Keywords: earthworms, invasive alien species, *Arthurdendyus triangulatus*, slurry, yield

Introduction

Soil organisms contribute to the fertility and sustainability of soils. The various roles of the macro-, meso- and microfauna are not fully understood but it is clear that there are complex interactions involved in the recycling and release of nutrients for plant uptake. In temperate European grassland the dominant soil macrofauna are lumbricid earthworms. The numbers and densities of earthworms varies considerably but typically there are 200-600 earthworms m^{-2} of pasture (Curry, 1994) equivalent to 2 to 6 million worms ha^{-1}. Therefore, the biomass in the soil can be up to 3-4 tonnes ha^{-1}. To put that in context, for an average field the underground earthworm biomass is equivalent or greater than the weight of livestock grazing above ground.

Earthworm diversity in pasture

The UK and Ireland are depauperate in earthworm fauna as the European land bridge flooded before post-glacial colonization. The British Isles have 26 earthworm species occurring in the wild (Sherlock and Carpenter, 2009). France, for example, has at least 180 species (Sims and Gerard, 1999). Furthermore some earthworm species live in specific habitats. The 'tiger worm' *Eisenia fetida* is associated with rotting organic substrates such as manure heaps and although common in farm-yards, it is typically scarce in open pasture. In Northern Ireland, 14 species of earthworm were found in pasture fields during a survey for the New Zealand flatworm, which largely agrees with studies in the Republic of Ireland (Curry *et al.*, 2008). The most prevalent species were: *Aporrectodea caliginosa*, *Allolobophora chlorotica*, *Lumbricus rubellus* and *Lumbricus terrestris*; whereas the rank order for percentage biomass was *L. terrestris* greatest followed by *Ap. caliginosa*, *L. rubellus* and *A. longa*. The reason for this discrepancy is because earthworm species vary greatly in size, e.g. the average weight of an adult *L. terrestris* was 3.19 g (n = 550, SD = 1.024) and *Ap. caliginosa* 0.29 g (n = 1,845, SD = 0.135). Earthworms can be divided into three basic ecotypes dependent on their positioning in the soil and which ecological niche they inhabit. These are: 'anecic' which are large earthworms such as *L. terrestris* that have vertical semi-permanent burrows; 'epigeic' or surface dwelling earthworms (e.g. *L. rubellus*) that have a high reproductive rate; and 'endogeic' earthworms (e.g. *Ap. caliginosa*), which are subsurface horizontal burrowers.

Contribution of earthworms to grass productivity

In Northern Ireland, grass is the predominant crop underpinning the dairy and beef industries. There are 800,000 ha under grass representing c. 60% of the Northern Irish landscape (DAERA, 2017b). The value of the grass crop is difficult to calculate but combining silage and grazing variable costs (DAERA, 2017a) gives a figure of £245 million per annum. If the value of grass is calculated as a concentrate-equivalent feed, then the value is much greater at c. £660 million.

Earthworm activity promotes plant growth and increases yield. European lumbricid earthworms were both accidentally and intentionally introduced to New Zealand and Australian pastures, where yield increased by 9-29% with the introduction of a single species *Ap. caliginosa* (Stockdill, 1982) and up to 61% with the introduction of *Ap. longa* (Baker *et al.*, 1999). In Irish studies in reclaimed peat soils, earthworms increased herbage production by 49% (Curry and Boyle, 1987) and in pot studies by up to 89% (Boyle *et al.*, 1997). A meta-analysis of 58 studies reporting the effects of earthworms on crops found that earthworm presence increased above-ground grass biomass by an average of 24%. For ryegrass, the predominant grass species in Northern Ireland, it was 34% (95% CI = 23.1 to 46.5) (Van Groenigen *et al.*, 2014).

Impact of the New Zealand flatworm on earthworms and grassland productivity

The New Zealand flatworm (*Arthurdendyus triangulatus*) was first found outside of its native habitat in Belfast in 1963 (Willis and Edwards, 1977). The flatworm is now widely distributed in Ireland, Scotland, northern England and the Faroe Islands. It has not been found in continental Europe. The flatworm is an obligate predator of earthworms. Although initially regarded as a curiosity, field sampling for earthworms in the 1980s drew attention to reduced earthworm populations where *A. triangulatus* was present (Blackshaw, 1990). Subsequently, an increasing body of work highlighted the potentially harmful effects of *A. triangulatus* on earthworm populations and, particularly, on anecic earthworm species such as *L. terrestris*. In a replicated field experiment, flatworm populations of 0.8 per m^2 (equivalent to wild populations) resulted in a 20% reduction in overall earthworm biomass (Murchie and Gordon, 2013). Therefore, *A. triangulatus* has the potential to reduce grass yield by 6.8% (20% reduction in earthworm biomass × 34% contribution of earthworms to ryegrass biomass). However, the 20% reduction in overall earthworm biomass comprised of a disproportionate reduction in anecic earthworm biomass of 74%. For an Irish climate, anecic earthworms are particularly important as their vertical burrows can aid soil drainage and prevent waterlogging, so the impact of *A. triangulatus* on pasture productivity could be even greater.

Effects of slurry on earthworms

Application of slurry is the most common agronomic practice for grass pasture. Slurry application often results in an initial earthworm kill close to the soil surface due to the high concentrations of ammonia and inorganic salts. However, in a long-term study that examined the effects of continual seasonal applications of slurry and fertilisers to a ryegrass sward over 33 years, earthworms largely benefitted from slurry application (Murchie *et al.*, 2015). There were differences in species-specific responses. Epigeic earthworms responded most positively to cattle slurry applications, with *L. rubellus* five times more abundant in the highest cattle slurry treatment; whereas juvenile *Aporrectodea* (but not adults) were most abundant in the inorganic fertiliser treatment. *Lumbricus terrestris* responded best to lower slurry application rates than the epigeic species. Pig slurry had little effect on earthworm populations, possibly because the beneficial effects of increased nutrients were offset by contamination with copper (fed to piglets as a growth supplement), which is toxic to earthworms.

Conclusions

This paper gives the 'good' news and the 'bad' news with respect to earthworms in Irish pasture. The good news is that what makes a sustainable habitat for earthworms is what makes a productive field for the farmer. Earthworms feed on organic matter in the soil, so inputs of dung, slurry and fertiliser are mostly beneficial, although with the caveat that earthworm species composition may alter. The bad news is that the New Zealand flatworm is reducing native Irish earthworm populations and this will have a knock-on effect on grass yield: potentially in the order of a 6-7% reduction in above-ground biomass. If *A. triangulatus* are in 70% of Northern Irish pastures (Murchie *et al.*, 2003), this equates to an average reduction of £15 per ha.

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Estimated nitrous oxide emissions from nitrogen fertiliser use on multispecies grasslands compared to monocultures

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Abstract

Grassland agriculture faces increasing demands in terms of sustainability; economic, social, and environmental. Soils are critical to sustainable agriculture, in terms of maintaining soil fertility and quality, protecting water quality and mitigating greenhouse gas (GHG) emissions. There is evidence to suggest that greater sward diversity may have benefits in this regard. We report results from SmartGrass; a three year field study at two sites in Ireland investigating grass sward diversity along a gradient from perennial ryegrass (*Lolium perenne* L.) monoculture to grass-legume mixes to more complex grass-legume-herb mixes of up to nine species. Results reported include estimates of nitrous oxide (N_2O) emissions from fertiliser nitrogen (N), soil temperature and moisture conditions, plant-available soil N, changes in soil organic carbon (C) and plant-available phosphorus (P). Estimated direct N_2O emissions from N fertiliser (g N_2O-N t DM^{-1} ha^{-1} yr^{-1}) decreased from 146 for the monoculture at 250 kg fertiliser N ha^{-1} yr^{-1} to 35 for the monoculture at 90 kg fertiliser N ha^{-1} yr^{-1}, to approximately 16 for the grass-legume and grass-legume-herb mixes, also at 90 kg fertiliser N ha^{-1} yr^{-1}. This was due to a combination of the grass-clover and mixed swards maintaining high DM yields at low fertiliser N input, and the fact that the fertiliser N for these treatments was applied entirely as urea. These results indicate significant potential for more diverse swards to mitigate GHG emissions from fertiliser N use in grassland agriculture.

Keywords: sward diversity, multispecies grassland, clover, nitrogen, nitrous oxide emission, greenhouse gas mitigation

Introduction

Agriculture faces the challenge of achieving sustainable, profitable production while maintaining environmental quality (Sutton *et al*., 2011). In Ireland, for example, ambitious national growth targets for agricultural output have been set. At the same time, Ireland, like other countries, must meet international environmental obligations in terms of water quality (e.g. Water Framework Directive) and greenhouse gas (GHG) emissions (e.g. EU 2020 targets), for example. Agriculture makes up 65% of Irish land area and 80% of this is grassland. The diversity of swards in Irish managed grassland varies widely, from intensively managed monocultures of selected perennial ryegrass (PRG; *Lolium perenne* L.) cultivar mixtures, cultivated and re-seeded on a regular basis, to extensively managed permanent semi-natural grasslands with much greater diversity (Sheridan *et al.*, 2011). Perennial ryegrass has become particularly predominant in the more intensively managed grassland systems, such as dairy, and now accounts for 95% of forage grass seed purchased in Ireland (DAFM, 2017). Perennial ryegrass monocultures require relatively high fertiliser nitrogen (N) input to support high DM yields and this fertiliser N use is associated with a range of environmental impacts, including GHG emissions, water quality and biodiversity. There is evidence to suggest that grass-clover swards and more complex multispecies swards of grass-legume-herb mixes can sustain relatively high yields at considerably lower fertiliser N input, thus minimising associated environmental impacts. The SmartGrass experiment established swards across a range of diversity, from PRG monoculture to complex mixes of grasses, legumes and herbs. Here, we report results of estimated direct nitrous oxide (N_2O) emissions from fertiliser N use associated with forage production for five of these experimental treatments to assess their potential for GHG mitigation.

Materials and methods

Plots (2 × 10 m) were established in September 2013 at UCD Lyons Research Farm in eastern Ireland on a silty clay loam Gleysol. The area has a temperate maritime climate with mean annual rainfall of 754 mm and mean annual temperature of 9.7 °C. Plots with a range of grass sward diversity were established, from PRG monoculture to complex mixtures of three grasses (PRG, timothy (*Phleum pratense* L.), cocksfoot (*Dactylis glomerata* L.)), three legumes (white clover (*Trifolium repens* L.), red clover (*T. pratense* L.), greater birdsfoot trefoil (*Lotus pedunculatus* L.)), and three herbs (ribwort plantain (Plantago lanceolate L.), chicory (*Cichorium intybus* L.), yarrow (*Achillea millefolium* L.)) (Grace *et al.*, this volume). We report on results from replicated treatments that were applied to 20 plots within that experiment. These treatments were sown (seed weight %) and managed for annual fertiliser N input as follows: 1) 100% PRG at 90 kg N ha^{-1} (PRG90), 2) 100% PRG at 250 kg N ha^{-1} (PRG250), 3) 70% PRG 30% white clover at 90 kg N ha^{-1} (PRG+WC90), 4) a simple mix of the three grasses (23% each) and three legumes (10% each) at 90 kg N ha^{-1} (SIMPLE90), and 5) A complex mix of the three grasses (20% each), three legumes (7% each) and three herbs (3% each) at 90 kg N ha^{-1} (COMPLEX90). Treatments receiving 90 kg N ha^{-1} yr^{-1} received it in the spring/early summer as urea in four equal applications. For PRG 250, 165 kg N was applied as urea in four equal applications and the remainder as calcium ammonium nitrate (CAN) through the rest of the grass growing year in four equal applications.

Recent studies (Harty *et al.*, 2016) have shown that, on average, direct emissions of N_2O from fertiliser N application to Irish soils are lower for urea than CAN, with an emission factor (EF) of 0.25% of applied fertiliser N, compared to 1.49% for CAN. These EFs were used, along with the recorded N fertiliser application rates and forms, and the measured grass DM yields (average over three years) from this experiment, to estimate the direct N_2O emissions from fertiliser N associated with growing a tonne of grass DM for each treatment.

Results and discussion

Estimated direct N_2O emissions from N fertiliser (g N_2O-N t DM^{-1} ha^{-1} yr^{-1}) decreased from 146 for PRG250 to 35 for PRG90, to approximately 16 for PRG+WC90, SIMPLE90 and COMPLEX90, representing a roughly nine-fold decrease from PRG250 to legume-containing mixes (Figure 1). This is due to a combination of the grass-clover and mixed swards maintaining high DM yields (Grace *et al.*, this volume) at low fertiliser N input, and the fact that the fertiliser N was applied entirely as urea. None of the N in urea is in the nitrate form, thus lowering the risk of N_2O emission. Results indicate that there may be significant potential for grass-clover and multispecies swards to support relatively high yields per ha with much reduced N_2O emissions. It should be noted that N_2O emissions from N fixed by legumes was not estimated and that results could be different under actual grazing conditions.

Legumes typically fix N and contribute most to overall DM yield later in the year, and application of N fertiliser at this time can suppress legumes. Also, urea tends to suppress legumes to a lesser degree than CAN. Therefore, N fertiliser was applied to the legume-containing swards early in the year as urea. This has a number of potential advantages: (1) due to typically cooler and damper conditions in the spring, the risk of ammonia volatilization from urea is lower, (2) application of N as CAN during the summer and the associated risk of ammonia volatilization and N_2O emissions, is avoided, (3) urea is a cheaper form of N than CAN. Such changes in fertiliser N practice with the adoption of grass-clover or multispecies swards would have the further advantage that the resultant reductions in GHG emissions could be relatively easily accounted for in a national inventory under 'Tier 2' IPCC, reporting as the activity data of form-specific fertiliser use (urea vs CAN) and the appropriate EF.

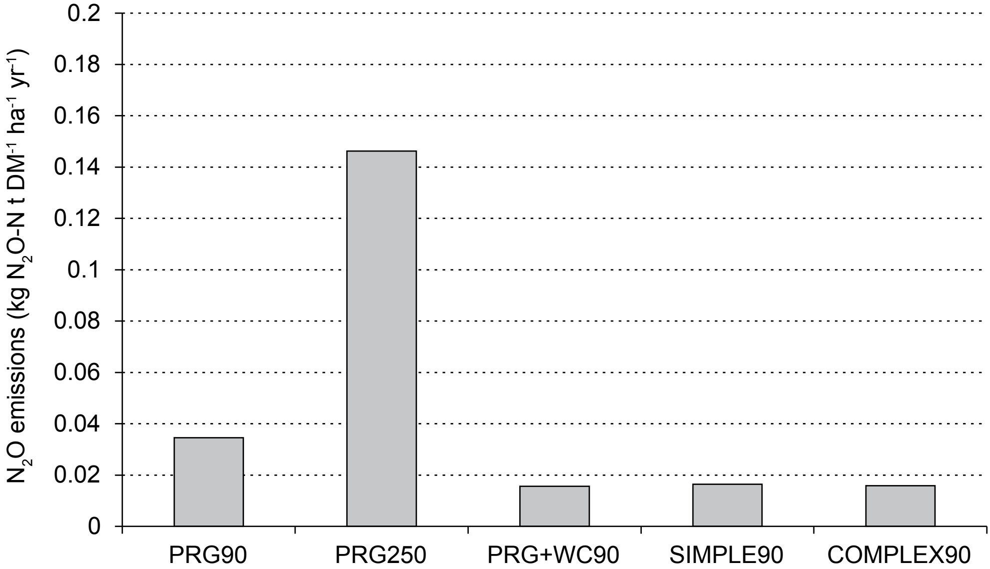

Figure 1. Estimated N_2O emissions associated with a tonne of grass DM production (kg N emitted as N_2O t DM^{-1} ha^{-1} yr^{-1}), using 'Tier 2' EFs of 1.49% for CAN and 0.25% for urea.

Conclusion

These results indicate significant potential for more diverse swards to mitigate GHG emissions from fertiliser N use in grassland agriculture.

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An evaluation of nutrient balances at the whole-farm and field scale on 21 Irish dairy farms

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Abstract

Nutrient balances were developed as an indicator of nutrient use efficiency (NUE) of fertiliser strategies being implemented on 21 dairy farms in Ireland. The dairy farms selected represent the variety of landscape, soil type, weather and environmental challenges typically found in the main dairy production regions in the south and east of the country. Field scale nutrient balance results revealed large variability within the farm boundary. Different landscapes, soil drainage classes and pasture cropping types do not have equal NUE and this variability in nutrient balances revealed the difficulty of matching nutrient input to off-take at the field level. The average nutrient balance per field (n = 384) for nitrogen was 138.6 kg ha^{-1} and ranged from - 132.2 to 362.1. The average phosphorus balance was 0.3 kg ha^{-1} and ranged from - 23.5 to 45.7 and average potassium balance was - 3.7 kg ha^{-1} and ranged from - 46.0 to 148.8 in 2016. Field scale targeting of nutrient applications, better matching input to off-take and capturing more of these applied nutrients in exported milk and meat products represent key opportunities to improve NUE on farms.

Keywords: nutrient balance, nutrient use efficiency (NUE), farm scale, field scale

Introduction

In Ireland, grass-based dairy production systems rely on high quality herbage as it is the primary input of the cows' diet. National fertiliser phosphorous (P), potassium (K) and lime use has declined since the 1990's, and national soil fertility, pH, P and K, has been in sharp decline since 2006 (Wall *et al*., 2013). As a result, approximately 10% of dairy farm soils currently have an optimum pH, P and K for intensive agronomic production. Most agricultural policies operate at the whole farm scale and only generally consider production intensity differences and landscape differences. In reality, most farms have multiple platforms, each with different stocking rate intensities or cropping strategies that exist at the field scale. Landscape features such as soil type, soil drainage class or topography also exhibit differences at this scale. Without the consideration of the impact these differences have on nutrient requirements of individual fields or platforms, the nutrient use efficiency (NUE) of a farm may decline. This project investigates the impact these factors have on farm and field scale nutrient balances on Irish dairy farms. The goal is to use nutrient balance as an indicator of nutrient sustainability and to model the environmental performance of these dairy farms.

Materials and methods

Twenty one farms were selected to represent different biophysical and management conditions across the south and south east of Ireland. Each field was soil sampled and analysed for P (Morgans P test), K, magnesium (Mg), pH and lime requirement. Soil test results were used to generate nutrient advice recommendations. Additionally, the soils were analysed by Mehlich III method and results were used to differentiate soils based on their nutrient cycling capacities. Nutrient balances were calculated at the farm scale and the field scale as follows: Nutrient Balance = Nutrient Inputs - Nutrient Off-takes. Nutrient inputs were nutrients in fertiliser, manures and concentrate feed. Nutrient Off-takes were nutrients in milk, meat and silage/hay. OVERSEER® (Wheeler, *et al*., 2007) was parameterised and calibrated for Irish dairy system conditions. It was used to model the nutrient flows and to estimate nutrient balance, N leaching and P run-off within Irish dairy farming systems. Linear regression analysis using R (R Core Team, 2013) was carried out to identify the most significant factors affecting field nutrient balance.

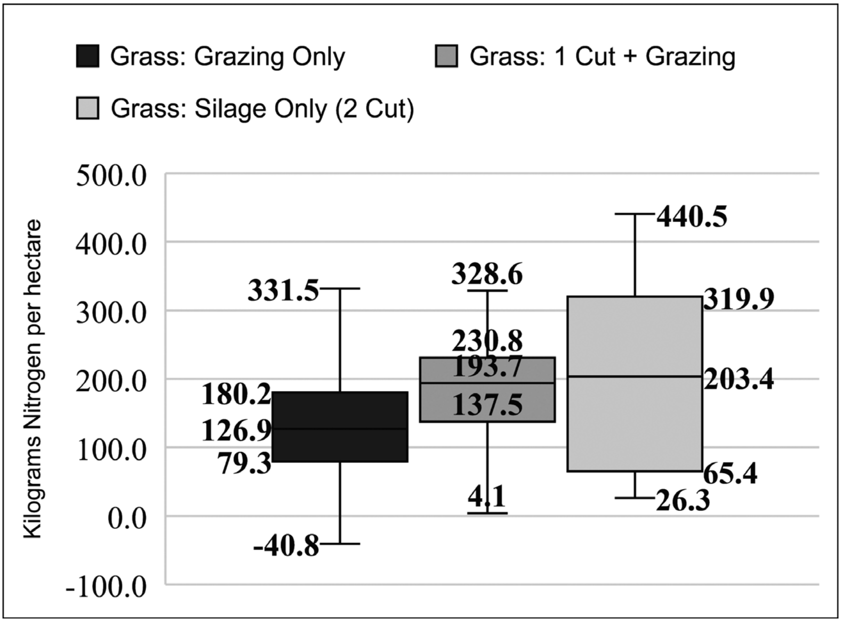

Figure 1. Shows the range in field scale Nitrogen balance values (kg ha-1) for fields in three different types of cropping strategies. The values in the middle of the boxes (126.9, 193.7, 203.4) are the median values for each of the strategies. By comparing median values, it is indicated that Silage Only fields tend to have a higher surplus N balance than Grazing Only fields.

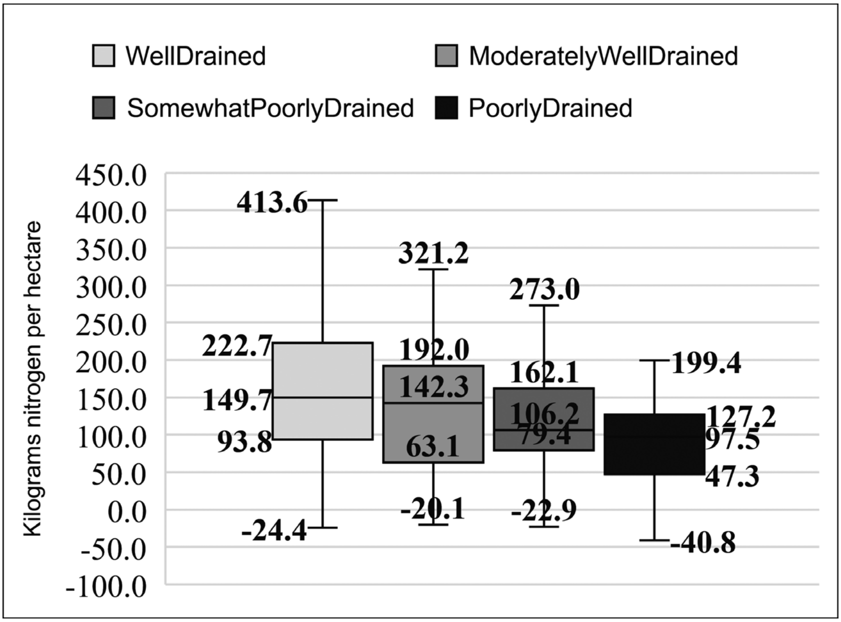

Figure 2. Shows the range in field scale N balance values (kg ha-1) for fields in four different soil drainage classes. This graph indicates that N surpluses differ depending on soil drainage class. When the median values are compared, it is indicated that fields with Poorly Drained soils have lower N surpluses than Well Drained fields.

Results and discussion

Chemical fertiliser imported had the most significant effect on nitrogen balance (R^2 = 0.40) followed by milk exported (R^2 = 0.28). The OVERSEER® model estimated on average 49 kg ha^{-1} N leached from the rootzone on these dairy farming systems per annum. Results for N balance at the farm and field scale both indicate N surplus. The farm scale balance has a smaller range and a smaller mean value. The field scale balance has a larger sample size and a bigger range in values.

The field scale approach is most useful when the data is split into appropriate categories or groupings based on cropping type or soil drainage class. These results indicate that there are opportunities to reduce N surplus and losses on dairy farms at both farm and field scales. Overall, it may be necessary to reduce the total amount of N imported to reduce N surpluses, however, increased N use efficiency could be achieved by more targeted distribution of N inside the farm boundary. For example, different N application rates could be targeted to fields with similar drainage class, grass production potential or stocking rate intensities. Nutrient management strategies across these platforms are often not optimised to match to the different grass production goals, as shown in Figure 1. Delineating fields and targeting N to fields with the largest nutrient requirement could result in both economic and environmental benefit. The range in field scale nutrient balance results can be driven by many factors; from soil fertility differences and management factors to landscape factors including soil type, drainage class and slope. Matching nutrient application rate and timing to field level biophysical factors could decrease P run-off loss risk on fields with high slopes. In the case of N, the identification of fields that have a different drainage class can better inform fertiliser planners which fields pose the greatest risk of N leaching. Figure 2 highlights the effect soil drainage class has on N balance. The average surplus is greatest on fields that have well-drained soils while the surplus is lowest on fields that are poorly drained. Well-drained fields require careful consideration when deciding on N rate, type and timing to minimise N leaching while poorly drained soils need similar consideration in relation to N loss through denitrification. Using OVERSEER® to model the N flows on these farms requires careful refinement of the input data for it to be completely suitable for modelling Irish farm conditions.

Conclusion

A fertiliser strategy that builds-in field level biophysical and nutrient requirements factors would be a progressive step towards improving the production, economic and environmental sustainability of Irish dairy systems. Field scale nutrient balances are an effective indicator of the impacts these factors have on nutrient use efficiency.

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Agri-environment measures for grassland habitats: halting the decline of biodiversity, or a missed opportunity?

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Abstract

Semi-natural grassland habitats have undergone a significant decline in recent decades throughout Europe, including in Ireland. Changes in farming practices such as intensification or abandonment can impact on the quantity and quality of threatened grassland habitats. Agri-environment schemes (AES) were established to promote farmland management practices that are more ecological and environmentally beneficial. Grassland conservation measures aim to halt the decline in the quality and quantity of grassland habitats by incentivising farmers to manage these habitats in a more environmentally sensitive manner. In an investigation of three widely-implemented grassland conservation measures in Ireland, there were significant differences in the quality of grassland habitat. Sites enrolled in the Natura measure had the greatest species richness, with a mean > 40 species per site (including approximately 17 species indicative of high botanical quality). Traditional Hay Meadow (THM) sites had the lowest species richness (mean: 29 species per site) and were often dominated by species associated with improved grassland. Despite this, financial incentives for the Natura measure were significantly lower than those for THM or species-rich grassland. A results-based approach, linking positive species indicators to higher payments, could help to halt the decline of semi-natural grassland habitats.

Keywords: agri-environment scheme, grassland conservation, semi-natural grassland

Introduction

The widespread decline in global biodiversity (including farmland biodiversity) represents a major conservation challenge. In Ireland, semi-natural grassland habitats, an important refuge for many floral and faunal species, have undergone a significant decline, mimicking the trend that has been witnessed throughout Europe. Measures to address the conservation of grassland habitats have been included in all iterations of Ireland's agri-environment schemes to date. Grassland conservation measures (i.e. payments for species-rich grassland (SRG); traditional hay meadow (THM); Natura 2000 grassland site (Natura)) are popular with land-owners, where incentives range from €75 ha^{-1} for Natura, to €314 ha^{-1} for SRG and THM. High participation, coupled with generous incentives, means that these measures represent a significant financial investment and policy instrument for protection of biodiversity in Ireland. There has, however, been no assessment of the effect of these grassland conservation measures on botanical diversity. This study compared the botanical species richness, abundance and community composition of sites enrolled in three AE grassland measures. We sought to compare the variability in the botanical composition within grasslands undertaking the same management measure (and thus in receipt of the same payment) as well as the variability between grasslands undertaking different grassland measures (and thus receiving different payments). Greater understanding of the botanical composition and quality of grasslands in receipt of AE payments will help inform policymakers on the cost-effectiveness of existing management criteria, as well as identifying ways of revising existing measures to improve their cost-effectiveness.

Materials and methods

Grassland surveys were undertaken on pastoral drystock farms in the midlands of Ireland between May and August 2013 and 2014. Twenty sites for each of the three grassland options (THM, SRG, Natura) were randomly selected from lowland grassland farms across counties Roscommon (20), Kildare (14), Longford (11), Laois (7), Offaly (6), and Mayo (2), resulting in a total of 60 sites. Botanical diversity was surveyed using 1 × 1 m quadrat sampling. Twenty quadrats were randomly located in each surveyed field, with all vascular plants rooted within each quadrat identified to species (according to Stace, 1997). Abundance values were assigned according to the Braun-Blanquet Scale, with this figure being converted to actual percentage cover values. The 20 quadrats per site were summed and the mean value was used to calculate a mean percentage cover value for each species per site. Positive and negative plant indicator species were based on recommendations by O'Neill *et al.* (2013), additional details in Ó hUallacháin *et al.* (2016). A comparison of species richness, and the richness and cover of positive and negative indicator species between each AE grassland measure was undertaken using generalised linear modelling and Kruskal-Wallis test in SAS.

Results and discussion

Grasslands in the Natura measure were significantly ($P < 0.001$) more species-rich than those in SRG and THM (Table 1). Natura grasslands had a significantly greater richness ($P < 0.001$) of positive indicator species than SRG and THM, both of which were similar (Table 1). The THM and SRG sites also had a greater cover ($P < 0.001$) of negative indicator species than Natura sites (Table 1).

Agri-environment schemes are an important policy mechanism for the protection of natural resources and provision of ecosystem services. To ensure the environmental effectiveness of AESs, schemes should be appropriately designed and managed, including specific objectives, clear justification and having a good ability to assess the intended environmental objectives. A key question for the design of AESs is: how to target participation and resources to those sites with the greatest environmental potential? In this study, for example, SRG sites that had only four positive indicator species were as eligible for payment as those with 24 positive indicator species. More targeted selection could prioritise entry of higher-quality sites by modifying the eligibility criteria; this would also help fulfil the recommendations of the European Court of Auditors that AE expenditure should be more precisely targeted.

Successful conservation measures should assess the environmental effectiveness of AESs and be appropriately costed. The European Court of Auditors in 2011 recommended higher payments for measures with higher environmental potential. Natura sites in the current study had significantly higher species richness, higher richness of positive indicator species and significantly lower cover of negative indicator species than either THM or SRG sites. Despite this, payment rates for Natura sites (€75 ha^{-1}) were lower than those for THM and SRG (€314 ha^{-1}).

Challenges, therefore, lie in appropriately rewarding those sites that are delivering the greatest environmental benefit or, alternatively, incentivising site management to increase their provision of

Table 1. Summary of positive and negative indicator species averaged across the sampled sites in each of the three grassland measures of AEOS.[1]

	Traditional hay meadow	Species-rich grassland	Natura
Mean species richness	29.05 ± 1.60^a	33.50 ± 1.79^a	40.05 ± 2.06^b
Range of species richness	17 - 47	21 - 54	27 - 59
Positive indicator richness	10.45 ± 0.92^a	12.30 ± 1.04^a	16.90 ± 1.04^b
Negative indicator species cover (%)	13.60 ± 1.53^a	14.07 ± 2.42^a	4.90 ± 1.19^b
Range of negative species cover (%)	0.94 - 20.68	6.34 - 45.11	0 - 17.13

[1] The table presents mean (± standard error of mean) richness and cover. F-values and significance levels are from general linear models (normal data) significance at $P < 0.05$. Means with the same letter do not differ significantly from one another.

environmental benefits. We found high variability in the botanical composition between sites in the same measure and subject to the same management criteria (and thus in receipt of the same payment under AEs). This highlights some of the limitations with AE measures that are based on payment by action. For example, the current study identifies the contrasting situation of a THM site containing only five positive indicator species and > 50% cover of negative indicator species being in receipt of the same payment rate (€314 ha^{-1}) as a THM site with 19 positive indicator species and < 10% cover of negative indicator species.

Conclusion

This study found significant differences in the species richness and botanical composition of grasslands enrolled in three different grassland conservation measures supported by the Irish AES. Natura sites had significantly higher species richness, more positive indicator species and lower cover of negative indicator species than THM and SRG. Despite this, Natura sites were in receipt of lower payment rates (per area) than THM and SRG.

An approach to address these challenges is to progress towards measures and schemes that are based on 'payment by results', as opposed to 'payment by action'. Payment-by-results approaches are based directly on the delivery of an ecosystem service; the more of the service that is provided, the higher the payment. They are more quantitative in their objectives, facilitate monitoring to assess effectiveness and allow more objective, transparent payment rates to be set. They also allow greater flexibility for farmers to innovate and achieve environmental targets.

Acknowledgements

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Recent soil fertility trends on intensive Irish dairy farms

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Abstract

Soil fertility is one of the main constraints in improving grass dry matter (DM) production on Irish grassland farms. This study investigated the levels of soil fertility from 2013 to 2017 on a matched sample of ten intensive dairy farms in Ireland. The farms sampled all paddocks for the main soil fertility elements, pH, P and K status every two years over a six year period. Grass DM production was recorded for each paddock during this period, but is only reported for the year of soil sampling. In total, 490 paddocks were analysed over the three years, which is an average of 16 paddocks per farm. There was a significant ($P < 0.001$) farm and year effect on all soil fertility parameters. Soil pH reduced initially from 6.33 (2013) to 6.218 (2015) to 6.62 (2017). Soil P increased from 7.7 to 8.9 over the three years. Soil K declined slightly in the mid project years, but was not at recommended levels for these farms. Grass DM production was high on the farms averaging >14.7 t DM ha^{-1} over the three years.

Keywords: grass production, soil fertility, lime, potassium, phosphorus

Introduction

Soil fertility levels are clearly limiting the capacity of Irish dairy farms to grow more grass DM. In 2014, only 10% of the farms soil sampled had optimal soil fertility as indicated by pH, P and K. On dairy farms, over 60% of farms samples had soil pH at sub optimal levels (< pH 6.3). While the levels of P application is governed by legislation on farms, the level of lime and K application levels is not, yet all three parameters are lacking on farms nationally. Since milk quota removal in 2014, there has been increased pressures on increasing grass production in Ireland. One of the areas that can have a major impact is increasing soil fertility levels on farms. In the past, soil samples have never been matched on a paddock basis over time and their improvement or decline in grass DM production tracked over time. Pasturebase Ireland (Hanrahan *et al.,* 2017), allows the compilation of farm grass DM production on a paddock basis on commercial farms. The objective of this study was to investigate the level of soil fertility on a matched number of dairy farms and establish the significant soil fertility parameters which influence grass output on these farms over a six year period. The farms in this sample are technically focused dairy farms, and participants of a dairy discussion group for > 15 years.

Materials and methods

This was a longitudinal study of grass performance on ten Irish grassland dairy farms between January 2013 and December 2017. The dairy farms were from a range of soil types operating grass-based, spring-calving herds in the Munster region of the Republic of Ireland. Soil fertility and grass DM production was measured on all grazing platform paddocks in 2013, 2015 and 2017. Soil fertility was quantified by individual paddock sampling at the beginning of each year. All participating farms required a Nitrates Derogation (Department of Agriculture, 2014) for each of the evaluation years, permitting application of between 170 to 250 kg organic nitrogen (N) ha^{-1} yr^{-1} across all farm paddocks in addition to 250 kg of inorganic N ha^{-1} yr^{-1}. A prerequisite for farm selection was for farmers to have a proven history of grassland management and measurement (based on records from PBI), which indicate the level and quality of data recorded. Throughout each of the years, all participating farmers were provided with grassland management training to ensure data is recorded correctly and coherently and that management practices were adhered to, to sufficiently test varieties and to disseminate new information. All farmers were members of a farmer discussion group which met on a monthly basis during the main grazing season.

The effect of Year and Farm on grassland parameters was estimated using PROC GLM (SAS Inst. Inc., Cary, NC, 2003). The grass variables investigated included: pH, P, K, total paddock yield (kg DM ha^{-1}), number of grazings, number of silage cuts, silage DM yield, grazing DM yield in the model. A simple linear regression, PROC REG (SAS Inst. Inc., Cary, NC) was used to test the relationship between total DM production, soil pH, P and K.

Data capture and storage – PastureBase Ireland

PastureBase Ireland is a web based grassland database which has a dual function of providing real time decision support for farmers while acting as a national grassland database, capturing information for benchmarking and research purposes. The system operates with the individual farm paddock (experimental unit in the current study) as the basic unit of measurement. All grassland information is recorded by the farmer through the web interface. Recorded data must satisfy predefined verification rules programmed into the system. Such verification checks include restrictions on grass cover estimations (0 to 3,500 kg DM ha^{-1}), silage yields (0 to 10,000 kg DM ha^{-1} yr^{-1}) and residual heights (2.5 to 9.0 cm). All measurements on PBI are described and calculated on a per hectare basis for individual paddocks. The operator builds a profile for each paddock, entering background information such as size, distance from parlour, altitude, aspect, drainage status, reseed date and method, sown varieties and soil fertility records.

Farmer inputs

Grass cover estimations are entered on a weekly basis during the main growing season, which is necessary to calculate grass DM production. Estimations are taken by using visual assessment (O'Donovan *et al*., 2002). As the farmer enters the grass cover estimations through the interface, there are five different paddock status options available for selection. These are: grass – land area which is available for grazing; been grazed – area which is currently occupied by livestock; silage – area earmarked for silage production; reseed – area which is under-going the reseeding process; other enterprise – area not in grassland. If a paddock cover reduces by greater than 200 kg DM ha^{-1} between two cover estimations, the user is prompted to enter defoliation (grazing or silage event) details into the system. A graze or cut date must be provided which allows the correct historic growth rate to be calculated which is required for the generation of DM yield estimations. This information is also required to calculate the average number of defoliations per paddock. Grass DM production was measured from 1 January to 31 December annually. Grazing and silage DM yields were assessed prior to cattle grazing or harvesting and was recorded through PBI using the methodology outlined by Hanrahan *et al.* (2017). As well as total herbage production, the proportion of grazed or conserved herbage, along with the number of grazings and conservation harvests for each farm was established.

Results

Both Year and Farm had significant ($P < 0.001$) effects on the soil and grassland management parameters. For the purpose of this paper the year effect is presented in Table 1. The number of grazings, number of silage harvests all significantly increased during the study period. Grazing DM increased by 2.2t DM ha^{-1}, silage DM yield declined by -0.825 t DM ha^{-1} and total DM production increased by 1.37 t DM ha^{-1}. The number of grazings increased significantly (+1.2, $P < 0.001$), while silage harvests declined by (0.1, $P < 0.01$). When all three parameters were regressed to grazing DM production, both pH (+ 1.06 t DM ha^{-1}) and K (+16.1) had significant ($P < 0.001$) effects on grazing DM output.

Discussion

The farms in this study were on average +5.6 t DM ha^{-1} higher than that produced by the average farms on the National Farm Survey farms (9.1 t DM ha^{-1}), therefore the farms in this study were in the top 5% of grass producing farms in Ireland. The dataset was slightly atypical as only one of the soil parameters were in deficit which is not the case nationally. Soil parameters reduced slightly in 2015 but increased

Table 1. Effect of Year on soil and grazing management parameters over a six year period.

	2013	2015	2017	SED	Significance
Soil pH	6.33	6.18	6.62	0.029	***
Soil P	7.9	7.0	8.9	0.396	***
Soil K	108.8	91.1	104.2	4.05	***
Number of grazings	5.5	6.1	6.7	0.1446	***
Number of conservation harvests	1.3	1.3	1.2	0.421	*
Grazing DM production (t DM ha^{-1})	9.21	10.43	11.41	265.4	***
Silage DM production	4.686	4.413	3.861	210.43	**
Total DM production	13.90	14.84	15.27	195.16	***

in 2017, showing that the farmers in the study put emphasis on improving soil fertility on their farms. Grass DM production increased substantially over the study period particularly grazing DM production, this was supported by increased number of grazings per paddock. Soil K never achieved recommended levels on these farms and is a clear area to improve. The improvement in grass output is very positive and shows that increasing both soil fertility and grazing management are vital to maintain high levels of grass productivity on farms.

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How long should a fen grassland field trial last? Reflections on the dry matter yield of a nitrogen fertilisation field trial on northeast German fen grassland over 55 years

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Abstract

In northeast Germany, a nitrogen fertilisation plot experiment has been continuously conducted since 1961. Compared to the unfertilised plots, the annual dry matter (DM) yield increased significantly at fertilisation rates exceeding 120 kg N ha^{-1}. Over the experimental period 1961 - 2015, the annual variability of DM yield was very high due to the highly variable weather and water conditions on the drained fen grassland site. Simulated reductions of the experimental period remarkably changed the trial results and led to different mean yield values and yield differences and even reversed slopes of the trend functions.

Keywords: long-term field trial

Introduction

Fen grassland is dependent on drainage. Drainage causes more or less heavy CO_2 emissions and is already under public pressure. Therefore, a serious evaluation of the agricultural prospects of drained fen grassland is needed, if possible, based on long term studies. Long-term field trials are ranking among the most valuable experiments in agricultural sciences. Due to the general demand to save labour and costs in most European countries, the maintenance of many long-term field experiments is not always assured.

In order to prepare an administrative decision on continuation or termination of a long-term nitrogen (N) fertilisation field plot experiment, we tried to describe how trial results would have changed if the trial had covered a few years only, had started later or stopped earlier. We did this in a simple and rather abstract way, not suited to replace a comprehensive agricultural and statistical evaluation of the experimental results which has already started. Although, in general, weaker results can be expected from a trial with a shorter experimental period, the magnitude of the impact of the timing and length of the experimental period on study results from our fen grassland far exceeded our expectations.

Materials and methods

At Paulinenaue (northeast Germany; 52°68'N, 12°72'E; 29 m a.s.l.; mean annual temperature 9.2 °C, mean annual precipitation 534 mm), a N fertilisation plot experiment on drained fen grassland (*Eutric Histosol*; peat formed by reed and sedges) has been continuously conducted since 1961. The annual N rate was varied in five steps: 0, 60, 120, 240 and 480 kg N ha^{-1}. All plots were cut three times per year, except for 2007, where only two cuts could be harvested due to extraordinary spring and summer rainfall and water logging on the entire experimental site. One third of the N fertiliser amount was applied to every cut. Potassium and phosphorus were given each year in early spring at the rate of 31.8 and 139.4 kg ha^{-1}, respectively. The trial was established in a complete randomised block design with four replications (Luthardt and Kreil, 1989; Käding and Werner, 1997). Compared to the unfertilised plots, the annual DM yield increased significantly at rates ≥ 120 kg N ha^{-1}, and we used the results of this treatment here.

This paper presents only the annual DM yields, which are discussed considering the entire period of 55 years compared to shorter simulated experimental periods, where the number of experimental years selected for the analysis was reduced in 20% steps (11 years), starting from 1961 at the beginning ('experiment stopped earlier') and from the end of the analysed trial period ('experiment started later') in 2015. In Figure 1, the whole experimental period 1961 - 2015 (1) was compared to the reduced periods 1961 - 2005 (2), 1961 - 1994 (3), 1961 - 1983 (4) and 1961 - 1971 (5), representing 'experiment stopped earlier'. In Table 1, the experimental periods 1972 - 2015, 1983 - 2015, 1994 - 2015 and 2005 -2015, representing 'experiment started later' as well as five 11-year-periods 1961 - 1971, 1972 - 1982, 1983 - 1993, 1994 - 2004 and 2005 - 2015 periods were additionally involved.

Results and discussion

Over the experimental period 1961 - 2015, the annual variability of DM yield was very high due to the annually varying weather and water conditions on the fen grassland site (Figure 1). Distributed over the entire experimental period, there were years with very high yield, e.g. 1965, 1973, 2004 and 2006, and years with very low yield, e.g. 1964, 1978 und 2007.

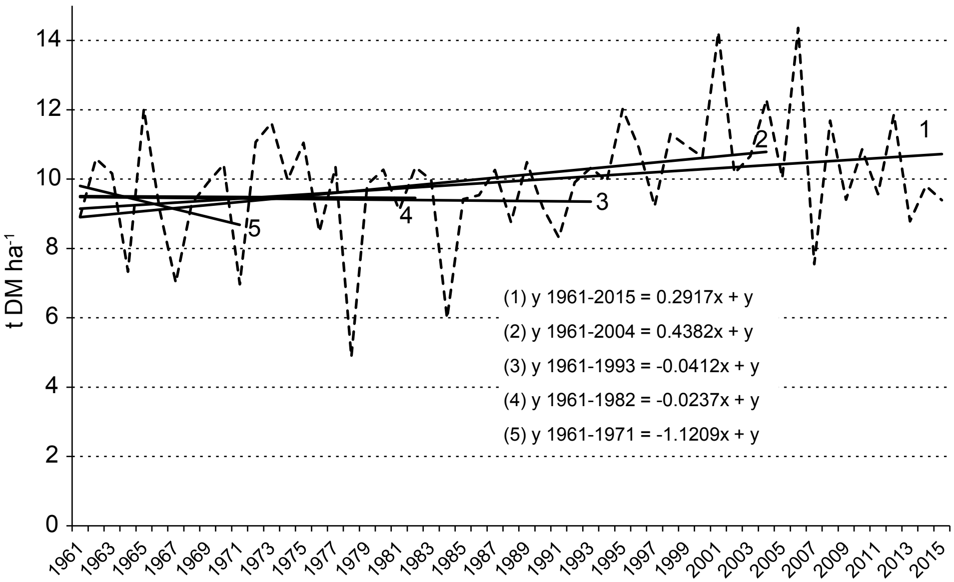

Figure 1. Variability of DM yield (t ha^{-1}) during different experimental periods (1) - (5) between 1961 and 2015.

Table 1. Mean yield (t DM ha^{-1}) during different experimental periods between 1961 - 2015 as compared to the mean 1961 - 2015 (9.94 t DM ha^{-1} = 100%).

20% periods (11 years)			'experiment started later'			'experiment stopped earlier'		
year	t DM ha^{-1}	%	year	t DM ha^{-1}	%	year	t DM ha^{-1}	%
1961-1971	9.24	93	1972-2015	10.11	102	1961-2004	9.84	99
1972-1982	9.72	98	1983-2015	10.24	103	1961-1993	9.42	95
1983-1993	9.29	93	1994-2015	10.71	108	1961-1982	9.48	95
1994-2004	11.12	112	2005-2015	10.30	104	1961-1971	9.24	93
2005-2015	10.30	104						

The simulated reductions of the experimental period changed the results considerably. The slopes of the trend functions reversed. During the periods (5), (4) and (3) from the beginning up to the first 33 years of the trial, the slopes had been negative, indicating a decreasing yield potential of the site over time. Considering 44 (2) and 55 (1) years of trial, we found just the opposite, i.e. an increasing slope of the trend, indicating an increasing yield potential of the site. The simulated reductions of the experimental period also changed the mean DM yields (Table 1). The results indicate that the 'earlier stop' led to lower mean DM yield and the 'later start' led to higher mean DM yield. The evaluation of the five 11-year periods DM yields led to the same trend.

Conclusion

After 55 years of trial, the DM yield trend was positive, indicating a positive agricultural prospect of the applied grassland management system. Only the relatively small reduction to 44 years led to a similar result. Shorter simulated periods resulted in a completely contrary overall conclusion of the trial. The largest differences in slope and DM mean yield were reported at the level of the 11-year-periods. It is likely that further reductions of the experimental period, e.g. to five or three years, would additionally increase the error.

As far as the data presented only give a first and very rough view on the agricultural results, a detailed statistical evaluation of the multiyear variation is also planned.

The slightly increasing yields after the mid 1990's correspond with the observed increasing temperatures and should be analysed with respect to climate change.

On more intensively used grasslands, there are a lot of questions which can be answered in field trials of three or five years. But on the fen site, the reduction of the experiment duration would have been very risky for the grassland yield evaluation, particularly under the rather continental climatic conditions. If at all possible, fen grassland trials should be designed as long-term experiments. This allows several multi-year comparisons at the same site, e.g. for different weather periods and the correct evaluation of the exceedingly dominant impact of the highly variable water situation.

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Impacts of long-term fertilisation on plant functional traits and diversity of grasslands on Reunion Island

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Abstract

On Reunion Island, grassland is the second agricultural land cover. Grasslands are present in the different ecological contexts of the island (from tropical at sea level to temperate climate on the mountain area). The fertilisation inputs are quite high. The long-term impacts of fertilisation on the vegetation have been studied mainly for temperate grasslands and impacts on tropical grasslands are not well known. The species pool is different in the diverse climates. The functional trait approach allows us to compare the dynamics of communities with different species. We studied the impact of fertilisation (quantity and type of inputs) on grassland communities along a climatic gradient. Since 2004, ten different treatments of fertilisation with three replicates (organic and/or mineral inputs from 0 to 600 kg N ha^{-1}) were applied on grassland in three different sites of the western part of Reunion Island (tropical site, temperate site and intermediate site). Three functional traits were measured: the specific leaf area (SLA), leaf dry matter content (LDMC) and vegetative height (H) in 2016. From these trait values, different variables were calculated (functional diversity, intraspecific variability indicators, etc.) and were compared between the different treatments and sites. The functional trait value was different between the three sites. The fertilisation affected only a few functional traits. These impacts were more important in the temperate climate than in the tropical one. This work contributes to our understanding of the long-term impact of fertilisation on the flora composition and can be used to propose adapted management of fertilisations (type or quantity).

Keywords: tropical permanent grassland, fertilisation, functional traits

Introduction

Reunion Island is a volcanic island in the Indian Ocean (21°05 south and 55°30 east). The climate on the island ranges from tropical at sea level to a temperate climate. The grasslands are the second-largest agricultural area of the island, comprising 20% of the agricultural area. The livestock density increased 60% during the period 1989 - 2010, resulting in increased fertiliser use. Most of the fertilisation on the Reunion Island is from mineral origin. This fertiliser induces several environmental drawbacks: water pollution, soil erosion, etc. Organic fertilisation is now suggested by different local institutions. To have a better understanding of the response of the grassland ecosystem, an experiment was installed in 2004 in three different agro-ecological sites at different elevations with ten fertilisation treatments. The experiment is still in progress. This paper presents the long terms impacts of these fertiliser applications on the grassland plant communities.

Materials and methods

The first site is characterised by a tropical climate (10 m a.s.l.) sandy soil and a dominate species *Chloris gayana*. The second site is localised at 800 m a.s.l. an intermediate climate (800 m a.s.l.) with andosol and the main grass species are *Pennisetum clandestinum and Paspalum dilatatum*. The high altitude of the third site (1,600 m a.s.l.) gives it a temperate climate and induces the dominant presence of temperate grasses such as *Dactylis glomerata, Bromus catharticus and Lolium arundinaceum.* These different plots were implemented by *Chloris gayana, Pennisetum clandestinum* and *Lolium perenne*. Ten treatments of fertilisation (Table 1) were applied with three replications on micro plots on each of the three sites. These micro-plots were of 6 m by 0.65 m. Each plot was cut around seven times per year.

On each of the 90 plots, we measured three functional traits for each species on five individuals at most. We measured the vegetative height on the field as the distance between the soil and the highly mature leaf stretched on the steam. This leaf is after sampled to measure leaf traits. The specific leaf area (SLA) was measured by the ratio between leaf area (measured on the fresh leaves) and the dry mass of the leaf. The leaf dry matter content (LDMC) was measured as the ratio between the dry and fresh mass of this last leaf. The field measurements were made in March for the two lower sites and in June 2016 for the highest sites just before the cuts. We compared the trait value per sites, per type of fertilisation, per N quantity, fertilisation treatment using ANOVA. We conducted a two-factor ANOVA to test the interactions between the site and the different treatments, quantity and type of fertilisations. Finally, we tested within each site the effect of treatments, type and quantity of fertilisation. The specific leaf area values were log transformed. Analyses were conducted using R core software.

Results and discussion

Table 2 presents the different results from the ANOVA. The functional traits were different between the sites. The individuals measured in the tropical climate condition had a higher height and LDMC and a lower SLA than those from the two other sites. The overall effect of the fertilisation treatment did not apply to all the variables. The LDMC was affected by the different treatment and the type of fertilisation. The results show also that the height was sensitive to the different fertilisation types. The interactions between sites and treatments were significant for most of the traits. On the tropical and intermediate site, the vegetative height was slightly affected by the type of fertilisation (plants were a little higher on mixed fertilisation). The vegetative height was affected by the different treatments only in the intermediate site with a higher height on mixed fertilisation. On the same site, the log SLA were affected by the type of fertilisation. On the temperate site, the LMDC was higher on the 0 input treatment compared to the other treatments. SLA and H were lower on the 0 input treatment.

Conclusion

Fertiliser application had different impacts on the functional traits on our three different sites. There were very few impacts on the tropical site and strong impacts on the temperate site. The long-term impact of fertilisation on temperate grassland on SLA and LDMC were already shown in the literature (Louault *et al.*, 2017; Marriott *et al.*, 2004).These results show the importance of the climate on the management of functional trait relationships.

Table 1. List of the different fertilisation treatments tested since 2014. The litter and the compost were from cattle.

Treatment	Description	Type	N quantity
T1	0 inputs		nil
T2	70 kg ha^{-1} yr^{-1} of N mineral	mineral	medium
T3	40 m^3 ha^{-1} yr^{-1} of litter	organic	medium
T4	40 m^3 ha^{-1} yr^{-1} of litter and 30 kg ha^{-1} yr^{-1} of N mineral	mixed	medium
T5	70 m^3 ha^{-1} yr^{-1} of litter	organic	high
T6	7.2 t.ha-1.yr-1 of compost	organic	high
T7	7.2 t ha^{-1} yr^{-1} of compost and 56 kg ha^{-1} yr^{-1} of N mineral	mixed	medium
T8	12 t ha^{-1} yr^{-1} of compost	organic	high
T9	12 t ha^{-1} yr^{-1} of compost and 48 kg ha^{-1} yr^{-1} of N mineral	mixed	high
T10	120 kg ha^{-1} yr^{-1} of N mineral	mineral	high

Table 2. Effects of the different treatments on the three functional traits, based on ANOVA. The values in bold indicate $P < 0.05$.

Site	Variables	Vegetative height	LogSLA	LDMC
All the site together	site	**0.00**	**0.00**	**0.00**
	fertilisation type	**0.05**	0.60	**0.00**
	nitrogen quantity	0.07	0.53	0.06
	treatment	0.22	0.28	**0.00**
	treatment*site	**0.00**	**0.00**	0.09
	quantity*site	**0.01**	**0.01**	**0.04**
	type*site	**0.04**	**0.00**	0.09
Tropical	fertilisation type	0.10	0.50	0.22
	nitrogen quantity	0.78	0.96	0.92
	treatment	0.06	0.40	0.52
Intermediate	fertilisation type	**0.03**	**0.00**	0.07
	nitrogen quantity	**0.00**	0.09	0.09
	treatment	**0.00**	0.10	0.24
Temperate	fertilisation type	**0.03**	**0.00**	0.07
	nitrogen quantity	**0.00**	0.40	**0.02**
	treatment	**0.00**	**0.00**	**0.00**

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The role of nitrification inhibitors for increasing sustainability on grassland farms

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Abstract

Increasing global demand for dairy and meat products coupled with society's demand to improve environmental sustainability is a global challenge. In Ireland, agricultural policy is striving to increase agricultural production while at the same time complying with EU directives for reducing greenhouse gas emissions and improving water quality. These policies clash in soils where nitrate availability controls both pasture production and emissions of both nitrous oxide (a potent greenhouse gas) and nitrate leaching (resulting in eutrophication). Controlling soil nitrate through the use of nitrification inhibitors results in dramatic reductions in environmental emissions and can sometimes lead to increased pasture production. The use of nitrification inhibitors is an expensive tool for which farmers often don't see agronomic benefits that justify the cost of their use. Combining nitrification inhibitors in inorganic fertilisers, animal feeds and manures can reduce the quantity of inhibitors required and reduce costs. The use of these techniques for inclusion of nitrification inhibitors can reduce both nitrous oxide and nitrate leaching by up to 80%. This paper will present a number of Irish studies investigating these alternative management practices for improving the sustainability of Irish farming systems.

Keywords: greenhouse gas emissions, nitrous oxide, ammonia, fertiliser

Introduction

Demand for dairy and meat products is predicted to increase dramatically in response to global population growth and changing consumption patterns, particularly in Asia. Ruminant agriculture is generally characterised with lower nitrogen (N) use efficiency with 70-95% of ingested N not utilised and excreted by animals (Oenema *et al.*, 2005). Globally, grasslands are important sources of the potent greenhouse gas nitrous oxide (N_2O) which results from nitrification and denitrification in soils. Use of N fertiliser, manure management and direct deposition of animal excreta are the main sources of agricultural N_2O which accounts for 60% of global anthropogenic N_2O emissions (Syakila and Kroeze, 2011). There is a global target to reduce greenhouse gas (GHG) emissions to limit global temperature rise to less than 1.5 °C. The EU has committed to reduce GHG emissions by 40% by 2030 with individual country specific targets being agreed under the Climate and Energy Package. Ireland has committed to reduce GHG emissions by 30% by 2030.

Increasing ruminant production coupled with societal demand to improve environmental sustainability is a global challenge. In Ireland, agricultural policy is striving to increase agricultural production while at the same time complying with EU directives reducing greenhouse gas emissions and improving water quality. These policies clash in soil where nitrate availability controls both pasture production and emissions of both N_2O and nitrate (NO_3) leaching (resulting in eutrophication). Controlling soil NO_3 through the use of urea based fertiliser with urease and nitrification inhibitors results in dramatic reductions in environmental emissions and can sometimes lead to increased pasture production. This paper summarises a number of recent studies investigating the effect of fertiliser type and urease/nitrification inhibitors on grassland production, N_2O and NO_3 emissions.

Materials and methods

A range of published Irish field experiments are summarised in this paper. Typically the experiments were conducted using small plots and microplots ranging in size from 2 × 8 m to 1 × 1m. A range of treatments (inorganic fertilisers and manures ± urease/nitrification inhibitors) were applied to representative soils across Ireland. The experiments were conducted in a randomised block design across a range of soil types. Agronomic plots were harvested between three and five times per year and dry matter and %N were determined using standard methods. N_2O emissions were measured using static chambers (0.4 m^2 and 0.1 m high) with four to six replicates per treatment. Ammonia volatilisation (NH_3) was measured using wind tunnels 0.5 m wide and 2 m long. NO_3 leaching was measured using monolith lysimeters (0.8 m diameter and 1 m deep). Annual DM yield, N uptake, cumulative N_2O and NO_3 loads (all in kg N ha^{-1}) were analysed using PROC GLM in SAS with treatment, block and soil type as the main factors.

Results and discussion

The effect of inclusion of the nitrification inhibitor dicyandiamide (DCD) with a range of inorganic and organic fertilisers can be seen in Table 1. The highest emission factor (EF) of 1.49% was observed for calcium ammonium nitrate (CAN), the effect of DCD was not investigated as 50% of the N in CAN is already NO_3. The EF for urea fertiliser was 0.25 which was 60% lower than for CAN. There are high NH_3 emissions associated with urea fertilisation, the inclusion of the urease inhibitor agrotain significantly reduced NH_3 emissions by 78.5% compared to urea (Table 1). Urea with agrotain had an N_2O EF of 0.4%, still significantly lower than CAN. The inclusion of DCD with urea and urea +agrotain further reduced the EF to 0.1% and NH_3 emissions were reduced by 74% compared to urea (Forrestal *et al.*, 2016). The switching of fertiliser formulation and inclusion of nitrification inhibitors can substantially reduce N_2O emissions. There generally was no DM yield benefit of using fertilisers with agrotain or DCD. There was significantly higher N uptake when urea was treated with agrotain (Forrestal *et al.*, 2017). The inclusion of DCD with urea or urea + agrotain had variable effects on yield with significant reductions in yield in some years (Harty *et al.*, 2017).

Amending animal feed with DCD has been shown to be an effective method to directly target urine patches and manure (Minet *et al.*, 2018). DCD was found to remain un-degraded and effective in manure that was stored over winter indicating that amending feed would result in manure with lower emissions when land spread (Minet *et al.*, 2018). The inclusion of DCD with cattle manure significantly reduced the N_2O EF by 88% (Table 1). DCD excreted in urine reduced the N_2O EF by 64% and reduced NO_3 leaching by 38 - 42% (Dennis *et al.*, 2012). There was generally no effect of DCD inclusion in manure or urine on subsequent grass DM yield and this would limit farmer use as it represents a substantial cost to production and may not be acceptable to the consumer. It is, however, an effective technology to reduce emissions.

Table 1. Mean N_2O emission factors (% of N applied) for a range of inorganic (CAN and urea) and organic (manure and urine) fertilisers and the % reduction due to DCD use.

Fertiliser type	Mean N_2O EF (% N applied)		Mean NH_3 EF (% N applied)	
	no DCD	with DCD	no DCD	with DCD
CAN	1.49[§]		4.1[$]	-
Urea[1]	0.25[§]	0.1[§]	27.9[$]	27.7[$]
Urea + NBPT[1]	0.4[§]	0.1[§]	6.1[$]	7.3[$]
Manure	0.83[¶]	0.1[¶]	-	-
Urine[3]	0.8[*]	0.29[*]	11.1[¥]	12.9[¥]

[§]Harty *et al.*, 2016, [¶]Cahalan *et al.*, 2014, [*]Minet *et al.*, 2018, [$]Forrestal *et al.*, 2016, [¥]Fischer *et al.*, 2016.

Conclusion

Switching fertiliser formation from nitrate based fertilisers on wet grassland soils can dramatically reduce N_2O emissions. The inclusion of the urease inhibitor with urea based fertilisers can reduce N_2O emissions compared to CAN and reduce NH_3 emissions compared to urea. The use of DCD with inorganic and organic fertilisers further reduces N_2O emissions but represents a significant cost to farmers with no consistent yield benefits to offset this cost. The use of DCD may also be perceived negatively by consumers.

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Does conservation status influence the temporal development of agriculturally used permanent grassland in Germany?

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Abstract

The preservation of grassland is an intensely disputed topic in the EU, in general, and in Germany, in particular. Preservation of grassland is topical mainly for two reasons: the protection of abiotic resources (e.g. erosion) and the preservation of species rich grasslands. Both reasons are addressed by the Greening of the Common Agricultural Policy. We analyse how the share and area of agriculturally used grassland evolved between 2010 and 2015 in dependence of the area's legal status and relevance for certain environmental aspects. The analysed categories are nature reserves ('Naturschutzgebiet'), sites of community importance (SCI), designated floodplains and grassland on organic soils. We use data of the Integrated Accounting and Control Systems from five German Federal States. Since 2014, the area of agricultural used permanent grassland increased in all investigated categories. In addition, in nature reserves and SCIs the share of permanent grassland managed organically is more than three times higher compared to normal landscapes.

Keywords: Common Agricultural Policy (CAP), land use change, Integrated Accounting and Control Systems (IACS)

Introduction

Grasslands provide a wide range of services. These services include the provision of forage and habitats for species rich communities as well as carbon storage, erosion protection and flood retention. In Germany, the conservation status of most grassland habitat types listed in the Habitats directive (EEC 92/43) is bad or insufficient and the population of many species typical of meadows and pastures declined dramatically (e.g. BfN, 2014). Despite their high environmental value, the area of permanent grassland (PG) in Germany declined by 7.0% between 2000 and 2010 (DeStatis, various years). This decline occurred despite the fact that the conversion of PG to arable land was limited from 2005 onward by Cross-Compliance. With the CAP reform of 2014, the preservation of PG was shifted from Cross-Compliance to Greening. Since 2015, conventional German farmers require a prior authorisation before they can convert PG into arable land. This authorisation is normally only granted if the farmer converts an area of the same size from arable land to PG at the same time. In this paper we examine how the area of PG evolved in different categories between 2010 and 2015.

Materials and methods

This analysis is based on data for five German Federal States (Schleswig-Holstein, Lower Saxony, North Rhine Westphalia, Rhineland-palatine and Brandenburg). These states account for 38% of the PG in Germany. The location and extent of agricultural land and PG, in particular, is extracted from the Integrated Administration and Control System (IACS) of the respective states. In this study, PG refers to areas which are classified as PG in the IACS and managed by entities (in the overwhelming majority farmers) applying for CAP payments. PG managed by entities not claiming CAP payments or areas not fulfilling the criteria of the CAP for grassland, as e.g. if the share of rush (*Juncus sp.*) or bare soil is too high are not included. Additionally, we extracted the information whether or not a farm is run organically.

Within the agricultural area, we delimit areas of interest for nature conservation by exploiting different data sources. In particular, we used the most recent maps of designated conservation areas, designated floodplains and peatlands. The used sources are provided in detail in Nitsch *et al.* (2017, p. 63 & p. 155 ff.). In this analysis we will present only the results for the following categories: nature reserve ('Naturschutzgebiet'), site of community importance (SCI), designated floodplain that are flooded at least once every 20 years (HQ_{20}), and grassland on organic soil. The area outside the areas listed in Nitsch *et al.* (2017, p. 63 & p. 155 ff.) is termed 'normal landscape' and more or less includes areas without any special legal status or a generally increased importance for the provision of environmental services.

The data are processed in a PostGres data base. Nitsch *et al.* (2017, p. 62 ff.) provide detailed information on the processing steps. The analysis is conducted for the years 2010 to 2015.

Results and discussion

In the investigated states, 46% of PG and 62% of arable land is located in the 'normal landscape'. In recent years, the development of the PG area shows a comparable trend over time irrespective of the category under investigation (Figure 1 left). From 2010 to 2013 the PG area decreased by 2.1 to 3.9%. The decline was stronger in categories having a higher legal protection status as a nature reserve, HQ_{20} and SCI. After 2013, we see a pronounced increase in the PG area. The strongest increase was in categories without any legal status, which experienced previously the lowest decline in the PG area. As a result, the PG area in 2015 deviated from the respective value in 2010 by -1.6 to +0.9%.

The increase in PG area since 2013 can be attributed to three reasons. First, the value of the payment entitlement converged to a flat rate. This convergence provided an impetus for farmers with surplus entitlements to rent areas, which had not received payments before. Second, in 2015 the payment entitlements for the Basic Payment were reassigned in Germany. As a consequence, farmers could claim payments for areas which had not received payments before without spending money to purchase entitlement. Third, the definition of PG eligible for the basic payment was extended with the introduction of the new CAP (cf. Luick and Röder, 2016).

The development of arable land deviates strongly from the development of PG (Figure 1 right). Up to 2013, the relative decline in the arable area was more or less comparable to the development for PG in the respective category. The decline was somewhat weaker on floodplains and slightly stronger in nature reserves and SCI. However, after 2013 we could only detect in the 'normal landscape' a moderate rise in the area of arable land (+1.5%). In particular, in SCI and nature reserves the area of arable land declined strongly.

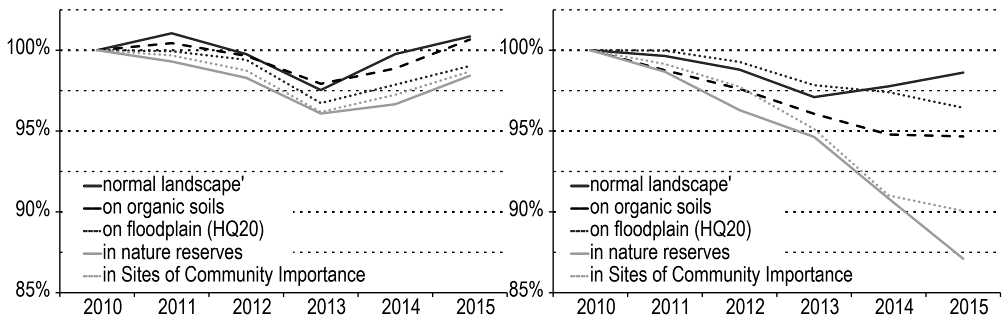

Figure 1. Development of permanent grassland (left) and arable land (right) in different categories in five German federal states between 2010 and 2015 (2010 = 100%).

The share of PG in organic farms differs markedly between the different categories (Table 1). While outside 'designated' areas the share reached only 5.1% in 2015, the respective values for nature reserves and SCIs are more than three times greater. In addition, the share of organically managed PG rose stronger in these protected areas.

Table 1. Development in the share of organically managed permanent grassland in different area categories in five German federal states from 2010 to 2015.

	2010	2015
Nature reserves	15.1%	17.0%
Sites of Community Importance (SCI)	15.2%	18.0%
HQ_{20}	11.1%	12.0%
Organic soils	7.7%	8.9%
'Normal landscapes'	4.2%	5.1%

With the introduction of the new CAP, the loss of PG in Germany came to a halt (DeStatis, various years). However, compared to 2010, the relative decline in the PG area is stronger in the protected areas compared to the 'normal landscape'. In SCI and nature reserves, the decline in the extent of PG was weaker than the decline in the arable land, prior to 2014. Therefore, it is fairly unlikely that the conversion of PG to arable land was the main cause of PG loss in these areas.

The high and increasing share of organic farming in SCI and nature reserves reduces the exposure of the biodiversity to pesticides and may lead to a reduced fertiliser input. However, this trend it is not unambiguous with respect to the preservation of species rich grassland as organic farms are classified as Green by definition (EU 1307/2013 Art. 43 ff.). Consequently, these farms may convert their PG without any implication in relation to their Greening payment. As the average tenure for arable land exceeds that for PG by more than €300 per ha (DeStatis 2017), this exemption puts PG under an unnecessary and latent pressure.

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Link between the number of grazing days and the mineral nitrogen fluxes in grazing systems

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Abstract

The Moorepark St. Gilles grass growth (MoSt GG) model has been developed to predict grass growth taking account of the water and nitrogen (N) fluxes at the paddock level. At grazing, the animal plays a specific role in the N fluxes due to urine and faeces deposition directly on the field. The MoSt GG model has been used to evaluate the effect of N fertilisation on the grazed grass N fluxes. The study was conducted using 10 weather years (2006 to 2015) from the INRA Le Pin experimental farm in Normandy at 4 different N fertilisation rates (0, 100, 200 and 300 kg N ha^{-1} yr^{-1}). Results show a clear link between the number of grazing days, yearly rainfall and the amount of N leached. The range of N leaching varies between 0 and 135 kg N ha^{-1} yr^{-1}. The number of grazing days during the year seems to be the best indicator of the contribution of N leaching risk.

Keywords: model, grazing days, nitrogen leaching, rainfall

Introduction

Nitrogen (N) fluxes at pasture are a complex interaction between the plant, the soil and the environment. During grazing, the animal plays a specific role in the N fluxes due to its grass intake and urine and faecal depositions on the field. Establishing the link between the animal (through the number of grazing days - GD), the weather (mainly rainfall), the N fertiliser applied and the N leached would be an asset for describing part of the environmental impact of grazing. To do so, the Moorepark St-Gilles grass growth (MoSt GG) model was used.

Materials and methods

The MoSt GG model was developed to predict grass growth taking into account the water and nitrogen (N) fluxes at the paddock level. Its grass growth component has already been described in Ruelle *et al.* (2018). The model can predict grass growth taking into account soil type, weather and grazing management. In this paper, the MoSt model was used with ten weather years (2006 to 2015) from the INRA Le Pin experimental farm in Normandy with four different annual N fertilisation (0, 100, 200 and 300 kg N ha^{-1}). The yearly average rainfall observed during those ten years was 723 mm (± 176). In every simulation all of the defoliation events correspond to grazing events. Grazing was simulated with a herd of 18 dairy cows fed a daily concentrate allowance of 3 kg as well as grass. The grazing dates were fixed for the 100 kg N ha^{-1} simulation. In that simulation, a grazing event occurred as soon as the pre-grazing height (from 9 cm to 12 cm depending on the rotation) was reached. The residence time was calculated by the model taking into account a grass intake of 16 kg DM cow^{-1} day^{-1}. The simulation with 0, 200 and 300 kg N ha^{-1} was run with the same herd on the same dates; the model adjusted the residence time to always reach a post grazing sward height of 5 cm. The outputs of the model in terms of grass growth, grass N content, number of grazing days, increase in soil mineral and organic N content due to the faeces and urine deposition, as well as the N leaching, were analysed. Every year, the N leaching and the autumn-winter rainfall (awR) were calculated as the sum of the daily N leached and the daily rain between 1 October and 31 March of the following year.

Results and discussion

The main outputs are presented in Table 1. The increase in N fertilisation level led to a curvilinear increase of cumulative grass growth (+27.8 kg DM ha^{-1} between the level 0 to 100 kg N and +12.8 kg DM ha^{-1} between 200 and 300 kg N ha^{-1}) and grass N content. Similarly, the number of grazing days increased as the N fertiliser application rate increased (from +193 days between 0 to 100 kg N ha^{-1} to +83 days between 200 to 300 kg N ha^{-1}). The increase in grazing days induced an increase in N returned through urine and faeces. The autumn-winter N leached is highly sensitive to the variation in N fertilisation applied and ranged between years from 0 to 102 kg N ha^{-1}. The increase in N fertilisation led to an increase in N leached due to a multiplicative effect of the higher biomass leading to more grazing days and the increase in grass N content intake (Vérité and Delaby, 2000). According to those authors, the number of grazing days per hectare is a good synthetic parameter to describe N leaching at pasture. For every increase of 100 days of grazing, the total N urine and faeces excreted by the animal increased by 27.6 kg and 13.8 kg N, respectively. Approximately 80% of the N from urine was returned directly to the paddock, with the remaining 20% captured on roadways and yards during the twice daily milking.

The N leached increased exponentially with the number of GD achieved per ha and per year (Figure 1a) as previously described by Vertès *et al.* (2008). With a similar response curve, the N leached is also very sensitive to the autumn-winter rainfall (Figure 1b). The highest values of N leaching correspond to a combination of the highest number of GD and of the awR. The equation of the exponential relationship between the number of GD per ha and the N leached is N leached (kg ha^{-1} y^{-1}) = $8.52\times e^{0.0018xGD}$. This equation explains 47% of the variation between year and between N leaching. The addition of the awR (mm) effect leads to N leached (kg ha^{-1} y^{-1}) = $(1.17+0.87\times(awR-289))\times e^{0.0013xGD}$, with 93% of the N leached variation explained.

The autumn-winter rainfall helps to describe the impact of the water drainage on N leaching as it improved the prediction in case of a low rainfall winter leading to a low level of N leaching.

Table 1. Description of the average (minimum-maximum) main outputs of the MoSt model linked to its nitrogen (N) sub-model for the simulation of ten weather years at four levels of N fertilisation.

Level of fertilisation kg N ha^{-1}	Cumulative grass growth 1000 kg ha^{-1}	Grass N content[1] %	Grazing days ha^{-1}	Increase of mineral N from faeces and urine kg N ha^{-1}	Increase of organic N from faeces kg N ha^{-1}	N leaching[2] kg N ha^{-1}
0	6.5 (3.2-9.8)	2.24 (1.99-2.64)	429 (180-702)	52 (26-99)	36 (15-58)	26 (5-50)
100	9.2 (4.7-13.4)	2.78 (2.49-3.18)	622 (288-954)	109 (59-184)	52 (25-79)	28 (3-62)
200	11.2 (6.1-16.3)	3.21 (2.89-3.63)	761 (378-1,134)	168 (93-271)	64 (32-95)	33 (2-77)
300	12.6 (7.0-18.5)	3.58 (3.23-4.00)	844 (414-1,278)	217 (123-336)	71 (35-106)	40 (0-102)

[1] Average N content of the grass fed to the animals.

[2] From 1 October to the following 31 March corresponding rainfall: average 409 mm (± 85).

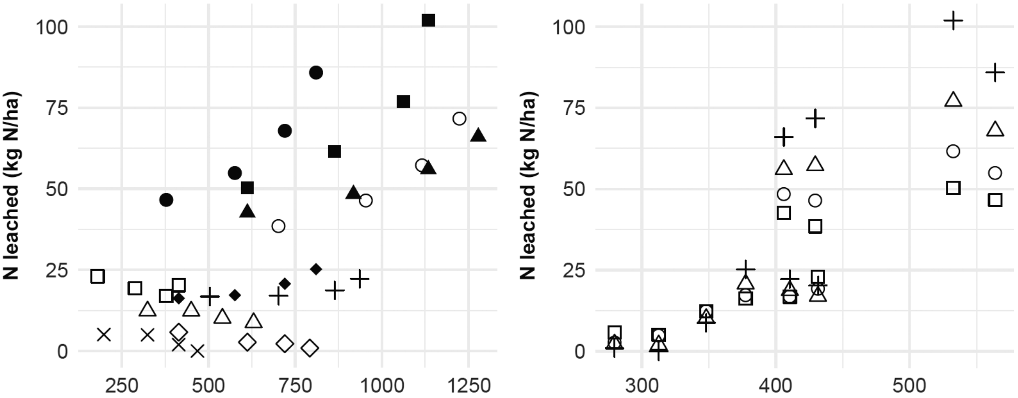

Figure 1. Relationship between the impact of (a) the number of grazing days and (b) the amount of autumn-winter rainfall on the N leached during the winter.

Conclusion

The number of grazing days during the year is the single best indicator of the contribution of N leaching risk. The combination of the two parameters, rainfall and grazing days, well describes the specific circumstances inducing leaching in autumn and winter, nitrogen availability from mineralisation, low grass growth and high drainage.

Acknowledgements

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A national typology for High Nature Value farmland in Ireland

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Abstract

We used farm-scale land cover and management data to describe a diversity of High Nature Value farmland (HNVf) types in Ireland. We identified six HNVf types; five corresponded to existing broad EU HNVf types and another 'Aggregate HNVf', was not previously described. Similar farm types occurred across geographically disparate parts of Ireland, indicating the need for policy supports that target each of the HNVf types rather than address specific geographic locations. This typology can facilitate better understanding of HNVf for policymakers and farm advisors and thereby aid the development of national policies and measures that better target, support and conserve HNV farmland.

Keywords: EU policy, rural development, farmland habitats, landscape conservation

Introduction

High Nature Value farmland (HNVf) is typically characterised by a combination of low-intensity land use, dominance of semi-natural vegetation and/or landscape mosaics, and is associated with high levels of farmland biodiversity. Due to the important role of HNV farmland in delivering environmental public goods such as biodiversity, clean air, clean water, stable climate and aesthetic landscapes, their identification, monitoring and support has been a policy requirement for EU countries since 2003. A lack of information on what exactly characterises a HNV farm is a major impediment to the application of policy supports for the conservation of HNVf. Three types of HNV farmland were initially described by the European Environment Agency (EEA, 2004) with the aim of being applicable across the EU. Keenleyside *et al.* (2014) provided specific examples of Whole, Partial and Remnant HNV farmland in various countries, with the aim of aiding the development and application of national policies. We describe the diversity of HNV farm types in Ireland, and the characteristics that distinguish the different types from one another.

Materials and methods

A total of 102 farms were sampled across ten different geographical sites in the Republic of Ireland with a high likelihood of occurrence of HNV farming, except for the island sites, where four farms were selected on each of the three islands off the west coast. All habitats within the farm boundaries were walked and identified. Farmers were surveyed about their farm enterprise and management details such as chemical fertiliser use and feed purchased. Combining the habitat information and responses, we calculated 29 variables relating to farm management, landscape and farmland biodiversity. Principal Components Analysis (PCA) was conducted on the variables and cluster analysis was used to group farms based on their inter-farm homogeneity, and was performed using the principal components scores from the PCA analyses. Euclidean distance measure and Ward's linkage method were used to identify clusters of similar farms to produce a typology. Resulting clusters were compared with the existing European HNVf classifications (further details are in Sullivan *et al.*, 2017).

Results and discussion

Our results indicate more specific types of HNV farmland in Ireland than those previously described. We identified six types of HNV farmland (HNVf) and describe them here; five correspond to existing known types EU of HNV farmland and another 'Aggregate HNVf', which has not been previously described. Management intensity had the greatest influence on the classification of the farms. Five to six key variables provided a summary description of each HNVf type: stocking density, proportion of farm area comprising semi-natural habitat, grassland or peatland, density of field boundaries; proportion of farm area comprising common land, proportion of area comprising Natura 2000. The mean values for selected key variables were calculated per cluster (Table 1).

Cluster 1, 'Whole HNVf farms with no commonage', typically contained lowland farms with low proportions of peatland and high proportions of semi-natural grassland (27%). Notably, these farms had no commonage land, and the average coverage of semi-natural habitats for this cluster was high (75%). Cluster 2, 'Whole HNVf small farms', contained farms smaller than those in the other clusters. On average, 45% of the area of farms in this cluster was commonage, with a high coverage of semi-natural habitats. Cluster 3, 'Whole HNVf large farms', comprised farms that were, on average, quite big, and had high proportions of semi-natural habitat cover (91%), most of which was peatland. Almost all of these farms had shares in commonage (45% of the farm area). Cluster 4, 'Whole HNVf commonage farms with improved agricultural grassland' had a lower average proportion of semi-natural vegetation than in the previous three clusters (68%). These farms were farmed more intensively than the previous three clusters. Clusters 1 to 4 all correspond to Type 1 HNVf (EEA, 2004) and Whole HNVf (Keenleyside *et al.*, 2014).

Farms in cluster 5, 'Partial HNVf', had high proportions of semi-natural habitat (55%), although this value is lower than that in Clusters 1 to 4. Field boundary density was also high (216 m ha^{-1}). This cluster appears to correspond to Type 1 HNVf (EEA, 2004) and Partial HNVf (Keenleyside *et al.*, 2014). A total of 21% of the farms analysed in this study were Partial HNV farms. Cluster 6, 'Remnant HNVf farms', had farms with a lower proportion of semi-natural habitats and highest stocking density (1.37 LU ha^{-1}). This cluster appears to correspond to Remnant HNVf (Keenleyside *et al.*, 2014). A subset of four farms in Cluster 6 had small areas of Annex I species-rich wet grasslands that, together, make up the continuous and very important Shannon Callows. This represents another type of HNV farmland that is linked to specific landscape-level habitats. We refer to this subset of Cluster 6 as 'Aggregate HNVf'. It would correspond to Type 1 HNVf (EEA, 2004) and is not described by Keenleyside *et al.* (2014).

Table 1. Average values for selected variables of the six types of HNV farmland.

Cluster	1	2	3	4	5	6
HNVf type	**Whole (- common)**	**Whole (small)**	**Whole (large)**	**Whole (+ common)**	**Partial**	**Aggregate**
Farm area (ha)	160	44	208	209	55	59
% semi-natural	75	81	91	68	55	28
Stocking density (LU ha^{-1})	0.45	0.48	0.31	0.67	0.62	1.37
Field boundary density (m ha^{-1})	93	138	39	64	197	180
% commonage	0	44	45	62	7.6	4.4
% Natura 2000	87	48	65	70	27	27
% peatland	6.1	61	80	63	26	6.4
% semi-natural grasslands	27	16	9.2	3.3	21	17

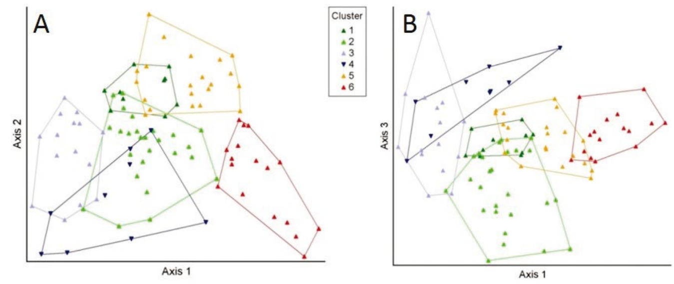

Figure 1. Results from PCA with the six HNV clusters included as an overlay of A) axis 1 versus axis 2 and B) axis 1 versus axis 3.

This typology relies on farm-scale data to help discriminate among different types of HNV farmland. In addition, farm-scale identification of HNVf types corresponds to the level at which management decisions are taken and CAP supports are implemented. Similar farm types occurred across geographically disparate parts of Ireland, indicating the need for policy supports that target each type of HNV farmland rather than address specific geographic locations. This typology can facilitate better understanding of HNV farmland at farm-scale for policymakers and farm advisors and thereby, aid the development of national policies and measures that better target, support and conserve HNV farmland.

Acknowledgements

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Dynamic of herbaceous biomass during the wet season in the Sahel

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Abstract

The Sahel makes up a transition zone between the extremely dry desert in the north and the sub-humid climate in the south. The vegetation growth in Sahel rangelands is driven by the highly seasonal rainfalls brought by the convective storms of the West African monsoon that reaches the Sahel in rainy season between June and October with a peak rainfall in September. Mean annual rainfall varies from 150 to 600 mm. In adaptation to the regular rainfall seasonality, solar radiation, temperature and air humidity, the herbaceous vegetation is largely dominated by short cycle annual plants, associated with more or less scattered woody plants among which deciduous dominate. Both resources are grazed by livestock in communal rangelands. Annual herbaceous germinate with the first rains, sometimes between May and July, depending on years and locations. Their growth starts slowly for a couple of weeks during which grasses seedlings establish their rooting system and tillers. The growing dynamic of the herbaceous vegetation during the rainy season is, however, not well understood. During the rainy season of 2017 from 24 June to 10 October, the weekly biomass growth of three rangelands plots in Northern Senegal was assessed. The biomass of herbaceous plants was measured using a destructive approach. The first rain in 2017 was quite early (end of June). However, the rain stopped after one month and the second rain wasn't until August. This unexpected rainfall shortage resulted in a cessation of vegetation growth. During this period, the grass did not grow and stayed in early phenological stages.

Keywords: Sahel rangelands, seasonal rainfall, herbaceous vegetation

Introduction

The Sahel region is one of the largest dryland areas in the world. It covers a 6,000 km belt spanning across ten African countries from the Atlantic Ocean to the Red Sea. The Sahel is characterised by low (150 - 600 mm yr^{-1}) and erratic rainfall (CV = 0.30) (L'hote, *et al.,* 2002; Dyer, *et al*., 2016). Extensive livestock production is the main economic activity. Animals mainly feed on natural savanna vegetation composed of scattered trees and an annual herbaceous layer (Hiernaux and Le Houérou, 2006). Herbaceous species grow during the short rainy season (one to three months of rainfall) and are exploited by livestock during both the rainy and the dry seasons. They also provide many other services such as carbon sequestration, soil erosion control, biodiversity conservation. The annual species germinated generally with the first rain. These species continue to grow during the rainy season (one – three months) until flowering, fructification, and then death. The dry grass is consumed by livestock during the dry season. The dynamics of the vegetation during the rainy season is a key parameter for the livestock production in pastoral systems. Understanding the dynamic of the rangeland during the rainy season would be useful knowledge for the prediction of the available biomass. In this work, we present the results of a weekly monitoring conducted during the rainy season from 3 July to 30 September.

Materials and methods

The study area is located in the sylvo-pastoral Ferlo region of Senegal in the Zootechnic research center of the Senegalese agricultural research institute in Dahra Djoloff (15°21' N 15°26' W). Three plots of 20 × 20 m area of natural rangeland were monitored throughout the rainy season of 2017. Two of the plots (P1, P2) were mainly dominated by *Zornia glochidiata* and the third (P3) by *Diodia scandens.* The monitoring commenced one week after the first rain event of 10 mm on 24 June. Each week, three quadrats of 1 m^2 were randomly placed on each plot. On this quadrat, the fresh herbaceous biomass were collected and dried to obtain the dry biomass. We evaluated the dynamics of the biomass. For each plot, we made an ANOVA to test the difference of biomass at each measurement date followed by a Tukey HSD test. We also calculated the daily gain in dry mass between two measurement dates.

Results and discussion

Figure 1 presents the biomass of the herbaceous mass monitoring during the rainy season and the rainfall events. For each plot, Table 1 presents the quantity of herbaceous mass in dry matter, the daily gain in biomass calculated between two measures. In the 2017 season, first rainfall occurred at end of June (88.5 mm between 24 and 29 June). Thus, between 29 June (day 4 after the first rain) and 27 July (day 34 after the first rain) only 3.5 mm of rainfall was recorded. The first rain induced a germination of the herbaceous

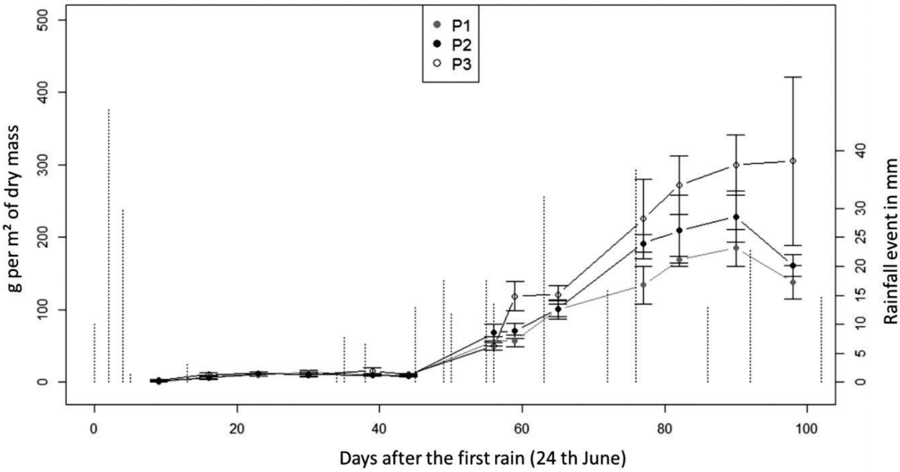

Figure 1. The mean dry biomass dynamic of the three plots [P1, P2, and P3] measured on the research center of Dahra Djoloff at each week after the first rain. Error bars represent the standard deviation. Vertical dotted lines represent rainfall events during 2017.

Table 1. Dry Biomass measured each week in daily gain in biomass. The letters correspond to the results of the Tukey HSD test.

Days after the first rain	Dry mass in g per m^2						Daily gain in g of dry mass		
	P1		P2		P3		P1	P2	P3
9	0.84	a	1.86	a	2.14	a	0.84	1.86	2.14
16	6.91	a	5.73	a	10.83	ab	0.87	0.55	1.24
23	9.77	a	11.98	a	11.65	ab	0.41	0.89	0.12
30	13.49	a	10.71	a	10.09	ab	0.53	-0.18	-0.22
39	9.78	a	9.72	a	15.67	ab	-0.41	-0.11	0.62
44	9.1	a	8	a	10.26	ab	-0.14	-0.34	-1.08
56	56.36	b	68.34	b	49.57	ab	3.94	5.03	3.28
59	57.46	b	70.91	b	118.8	ac	0.36	0.86	23.07
65	100.4	c	101.2	b	121	bc	7.15	5.06	0.37
77	134	cd	191.6	cd	225.4	cd	2.8	7.53	8.7
82	168.9	de	209.1	cd	272.2	d	6.99	3.52	9.37
90	185.8	e	228.3	d	300.1	d	2.11	2.4	3.48
98	138	cd	160.9	c	305.12	d	-5.98	-8.43	0.63

covers. However, the break in the rainfall stopped growth at a biomass of about 10 g m^{-2}, which led to a decrease of the biomass. Between 28 July and 26 August, nine rainfall events occurred totaling 123 mm of rainfall. This induced a quick increase in the herbaceous layers. The growth stopped around day 90 and started to decrease until day 98 for the plots P1 and P2.

These results show that the dynamics of the annual herbaceous are strongly linked to the rainfall events. The reparation and regularity of the rainfall are quite important parameters on the biomass production of rangeland, more so than the sum of rainfall in the year.

In the year 2017, the first rainfall events were not useful for the production of the biomass. The last rainfall also did not contribute to the biomass. Indeed, with annual species, the plants stop growing when flowering and seeding. Continued monitoring will provide a better understanding of the dynamics of the biomass of Sahelian rangelands.

It seems that the best production will be obtained when the rainfall is quite regular during the rainy season. A break during the rainy season has a strong consequence on the biomass production. Furthermore, the rainfall at the end of the season seems to not be useful. An early season will induce a higher biomass than a season with a later start.

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Balancing energy transition in Germany: how will it influence permanent grassland? A Delphi-study

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Abstract

Many governments worldwide see the German Energy Transition (*Energiewende*) as a success story. However, *Energiewende* remains wood-biomass-based and is still not able to reduce greenhouse gases (GHG) substantially. Today, permanent grassland (PG) is increasingly recognised as a GHG sink, but previously, politicians have prioritised having a safe energy supply along with 'green' energy from biogas, which favours maize over PG, causing net-C-losses. Between 2004 and 2011, policy incentives to increase biomass production in agricultural areas inadvertently resulted in the cultivation of PG and conversion to energy crops. Yet, climate protection is only one side of the coin: an immediate reaction to the Fukushima disaster, *Energiewende* hastily decreed the end of nuclear power and its replacement with safer energy sources. A new market-based system encouraging deployment of renewables was introduced in Germany in 2017. Our paper examines which policies are needed to avoid the repetition of past failures. We outlined recommendations, focusing on development and the implementation of an integrated policy framework, ensuring sustainability of PG use. This policy framework strives for an optimal balance between intensification, extensification and conversion of PG and stresses the necessity for a more effective implementation of emissions trading.

Keywords: permanent grassland, Energiewende, bioenergy, climate change, climate policy

Introduction

Conversion of PG into arable land causes GHG emissions: after PG conversion soils lose more than 50% of their original C (Guo and Gifford, 2002). In Germany, between 2004 and 2011, the area under maize cultivation increased by more than 700,000 ha (40%) (DeStatis, various years). During the same period, the area of PG declined by 270,000 ha. Conservative assessments show that at least a quarter of the PG decline can be attributed to the conversion of grassland into arable land to grow maize for biogas substrates (Laggner *et al.,* 2014). In 2016, only 12.6% of Germany's primary energy sources were 'renewables' (including maize on former PG); biomass accounted for 70% of the 'renewables' (UBA, 2017).

This conversion resulted from the incentives for biogas generation, set by the Renewable Energy Sources Act (EEG), first established in 2000. Today, the incentives that caused PG conversion are seen as a mistake (Nitsch *et al.*, 2012; Luick, 2017). In 2017, a new support system for renewables, based on market tenders, was introduced through the amendment of the EEG in Germany (BMWi, 2017). It is unclear what impact this system will have on the PG area in Germany up to 2030. Moreover, following the obligations under the Paris Climate Agreement, Germany strives to reduce GHG emissions by around 90% and become 'nearly GHG neutral' by 2050 (BUMB, 2016). Currently, decision-makers recognise PG as a potential GHG sink. As such, permanent grassland is part of the CAP Greening, as well as regulative laws at national and regional levels. From years of decline, the PG area has increased slightly, however, no strong protection is guaranteed by law. Several studies have found policy measures for PG protection inadequate (e.g. Nitsch *et al.*, 2012; Troost *et al.*, 2015). Current policies choose the preventive approach towards PG conversion but do not offer incentives for a quantitative increase of the PG area, i.e. renaturation of organic soils. The drainage of organic grassland soils in 2015 released 25,255.7 kt of CO_2 equivalents (UBA, 2017).

The objective of our study is to formulate policy recommendations to ensure inclusion of PG (focusing on the quantitative state) in climate protection and energy policies in Germany. The following research questions were formulated: (1) What alternative futures exist for the quantitative state of PG areas in Germany under different climate protection and energy policy scenarios in the medium time-horizon (2030)? (2) Is there an 'optimal' future policy scenario to prevent the conversion of PG for energy crop cultivation?

Materials and methods

We constructed and analysed policy scenarios, determining the medium-term future of PG in Germany. The construction and analysis of the scenarios followed the guidelines by Börjeson *et al.* (2006) was supported by the 'disaggregative' Delphi survey (see Tapio, 2002), comprising of three rounds of questionnaires. Twenty national-level experts representing the scientific sector participated in the Delphi survey.

Results and discussion

Four climate protection and energy policy scenarios were developed in our study: 'Smart Meadow', 'Carbon Market', 'Status Quo', and 'Techno Field' (Table 1). Each scenario represents consistent and plausible policy framework, determining the alternative future states of PG until 2030. Thus, scenarios were analysed to identify appropriate political instruments for prevention of PG conversion. Comparative analysis of the scenario outcomes for the PG area shows that there is substantial variation in PG area across scenarios (Figure 1).

The scenario 'Smart Meadow' has the potential to maximise the total PG area in Germany in the medium-term. However, the experts indicated that the implementation of 'Smart Meadow' can result in negative economic outcomes in rural areas by reducing the number of income streams for farmers. To prevent this potential negative externality, the policy recommendations outlined in this study are based on the combination of the scenario 'Smart Meadow' with the scenario 'Carbon Market'. The latter scenario includes payments for ecosystem services (i.e. climate regulation through the provision of GHG sinks) and therefore, has potential to compensate for the lost income observed with 'Smart Meadow'. Furthermore, according to the expert assessments under current socio-economic framework conditions, the implementation of the scenario 'Carbon Market' seems more feasible than that of 'Smart Meadow'. Therefore, the policy measures (Table 1) introduced in these scenarios inform the key recommendations for quantitative grassland protection.

The recommendations encompass implementation of an integrated policy framework encouraging good management practices, including sustainable (free-range) meat and milk production by raising green

Table 1. Climate and energy policy scenarios until 2030 in Germany, indicating the characteristic policy measures.

Scenario	The most characteristic policy measures
Smart Meadow	An integrated policy framework aiming at sustainable use of PG (encouraging good management practices); strict protection of PG on the C-rich soils; policy, encouraging payments for ecosystem services; limited use of biomass from PG for energy and heat generation.
Carbon Market	Political incentives for binding and storing GHGs in the newly created grasslands and converting the former arable land into PG; provision and conservation of the C-sinks is attractively rewarded; market incentives for utilising biomass from PG in energy and heat generation.
Status Quo	Policy measures for the gradual reduction of the biomass-based energy and heat production until 2030; the decentralised regulation structure of the land-use changes in the agricultural sector: sanctions and permissions for the conversion of PG in some federal states.
Techno Field	State incentives for development of technological solutions with the aim to achieve the GHG reduction targets by increasing efficiency of the existing processes; expanding deployment corridors for the energy and heat generation from biomass; no policy incentives for binding and storing GHGs in the newly created grasslands and former arable land.

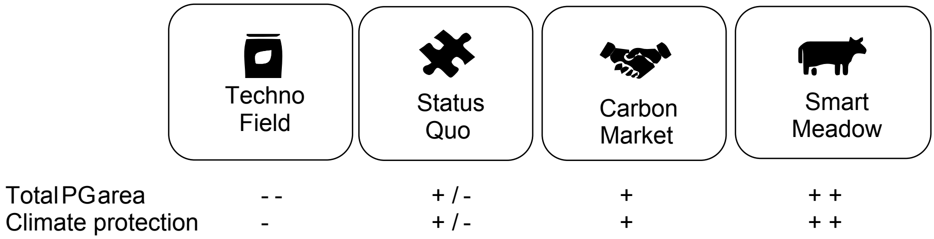

Figure 1. Total PG area and climate protection relevance in scenarios 'Smart Meadow', 'Carbon Market', 'Status Quo' and 'Techno Field'.

fodder use rates and reducing the use of feed pellets. Specifically, binding and storing GHGs in newly created grassland (i.e. former swamps and (re-)converted arable land) needs to be encouraged through further and more effective implementation of emissions trading and other public payment schemes for ecosystem services. It could be financed by shifting CAP subsidies from the first pillar to the second. Meanwhile, policy incentives for biomass energy and heat production from arable land need to be terminated. Furthermore, stronger market stimuli encouraging the farmers to utilise PG biomass for power and heat generation need to be introduced. Nonetheless, using PG locally as a source of green fodder should be prioritised. Additionally, sustainability certification in heat and energy generation from biomass needs to be subsidised. Finally, development and improvement of technologies for i.e. heterogeneous PG biomass production from high nature value grasslands is of vital importance.

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Grazing for carbon

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Abstract

The potential of grasslands as a carbon (C) sink in Europe is large despite the number of uncertainties related to the effect of grazing systems on C sequestration. The EIP-AGRI Focus Group (FG) 'Grazing for Carbon', a temporary group of 20 selected European experts from research and practice, shared knowledge and experience from different disciplines on the relationship between grazing and soil C. The FG explored grazing management strategies, drivers and barriers for different grazing systems, as well as tools and business models to support them successfully. The overall aim was to identify how to increase the soil C content in grazing systems. Six priorities were addressed: the effects and trade-offs associated with approaches to sequestering C in different grazing systems, the effect of grazing on C and soil nutrients, the role of plant mixtures and native species, general guidelines for optimal grazing, effective monitoring of soil C as a tool for soil quality evaluation and incentives to promote the adoption of grazing systems to optimise soil C content.

Keywords: carbon, focus group, grasslands, grazing, management, sequestration

Introduction

It is commonly understood that the potential of grasslands as a carbon (C) sink is large and promotes soil quality improvement by improving the organic matter content and thus soil physical properties. However, there are several, conflicting views with respect to the effects of grazing systems on C sequestration in Europe (e.g. Thornley and Cannell, 1997). It is currently unclear to what extent grazing systems can contribute to C sequestration and related greenhouse gas emission mitigation. The aim of this study was to explore the different existing grazing management systems with their respective drivers and barriers, and tools and business models to support them successfully. One way to establish and assess innovative grazing strategies that are promising for C sequestration is through multi-stakeholder approaches that unite experts from practise and from science.

The EIP-AGRI FG 'Grazing for Carbon' was established to assess how to increase the soil C content in grazing systems. Focus groups are temporary groups of 20 selected experts from research and practice throughout Europe. The experts' views and experiences were summarised into six thematic priorities: (1) the effects and trade-offs associated with approaches to sequestering C in different grazing systems; (2) the effect of grazing on C and soil nutrients; (3) the role of plant mixtures and native species; (4) general guidelines for optimal grazing, to be adapted and adopted in different parts of Europe; (5) effective monitoring of soil C as a tool for soil quality evaluation, and (6) incentives to promote the adoption of the best grazing systems. The topics were analysed through the drafting of 'mini-papers' encompassing a brief review of literature, ideas for operational groups (to be funded by rural development programs), research needs from practice and further developments.

To improve understanding of strategies towards better soil C management in grazed grasslands, a synthesis of empirical data of grazed grassland experiments conducted by the FG found sequestration to be 0.8 ± 0.2 Mg C $ha^{-1}yr^{-1}$ (rates ranging from losses to gains of more than 1 Mg C $ha^{-1}yr^{-1}$ (e.g. Soussana *et al.*, 2010; Conant *et al.*, 2017)). Despite this, there is little information on region-specific appropriate grazing management practices that sequester C or, equally importantly, maintain the current C stocks in the soil. Good grazing management is usually good for the environment and for people (food quality, income), while poor grazing management increases risks of the degradation of natural resources and yields. Improved grazing management may increase soil C content, e.g. by adjusting animal stocking rates or periodically removing grazing livestock to prevent overexploitation. The effect may vary depending on the timing, frequency and intensity of grazing, as well as pedo-climatic factors.

Increased plant diversity (mixing plant species, legumes, functional types or traits) has been reported to enhance yield and soil organic C (e.g. Kirwan *et al.*, 2007; Fornara and Tilman, 2008). However, there is also uncertainty due to scarcity of biodiversity-function experiments including grazing and insufficient information about underlying mechanisms triggered by plant diversity and acting under different grazing managements.

To optimise grazing for C, guidelines are required. Currently, a range of grazing guidelines exist in Europe, from simple to complex, and they are better developed in some regions/grazing systems than in others. They focus on important issues like grazing infrastructure, herbage utilisation, regrowth intervals, stocking rate and measurement tools. However, grazing guidelines generally do not yet consider soil C sequestration.

Effective monitoring of soil C is required to document the provision of C sequestration services by farmers/land managers. There are two main viable ways to do this: (1) measure the soil organic C content or the soil organic matter directly over time and use these data to estimate the change in C stocks (gold standard), and (2) register farm activities or indirect indicators of farm activities, calculate their potential for increasing C storage, and monitor only those activities. Usually the latter is a cheaper approach due to less intensive sampling, but it relies either on prior data or on modelling to identify relevant farming practices and quantify their effect. The two options are not mutually exclusive.

Incentives to promote the adoption of the best grazing systems must be targeted towards the appropriate stakeholders. Incentives can be policy driven (e.g. EU, national or regional policies, alleviating, simplifying actions), market driven (e.g. private production standards, voluntary C markets and funds, labelling) or farmer driven (e.g. influencing social norms and the mind-set of farmers by public campaigns; recognising the intrinsic value of C sequestration). Since improvements in grazing management and associated increases in C sequestration can be reversed, it is important that incentive schemes also take a long-term view. Finally, they may lead to more indirect valorisation by consumers, industries and distributor companies. Good examples of incentive schemes combine monetary and non-monetary compensation.

Conclusion

The strategy of the EIP-AGRI Focus Group, i.e. combining stakeholders from practise and science and from different disciplines in one group, has led to a clear overview of important issues with respect to C in grazing systems. Grazing systems are important for C storage. Optimal grazing management should be focused on additional C sequestration and on maintaining current C stocks.

Acknowledgements

This paper is based on the work of the Focus Group 'Grazing for Carbon' (https://ec.europa.eu/eip/agriculture/en/grazing-carbon), which was organised by the European Innovation Partnership for Agricultural productivity and sustainability (EIP-AGRI) supported by the European Commission. The paper represents solely the views of the authors and the European Commission cannot be made responsible for its content.

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Dairy farming and biodiversity: seeking for a better balance

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Abstract

Sustainable agriculture is an important component of many of the 17 Sustainable Development Goals agreed upon by the UN in 2015. However, the trend in agriculture is moving in a non-sustainable direction. Agriculture is one of the major drivers of biodiversity loss. Next to biodiversity loss due to habitat destruction by conversion of natural lands into agriculture, intensification of agriculture has led to a strong decline of specific farmland biodiversity. Furthermore, many agricultural landscapes face pollution by pesticides and fertilisers and encounter depleted soils and erosion due to unsustainable farming practices. This is threatening biodiversity, complete ecosystems and the ecosystem services on which agriculture itself depends. Moreover, the pressure of feeding an increasing number of people in combination with a change in diets towards more animal protein puts a lot of additional pressure on the current available agricultural lands and nature areas. We propose an holistic approach for sustainable agriculture that contributes to the development and implementation of sustainable practices in dairy production that make use and support biodiversity and ecosystem services. A dairy production system based on the full potential of (functional agro) biodiversity provides opportunities to create a resilient system.

Keywords: agriculture, biodiversity, sustainability, ecosystem services, conceptual framework

Introduction

Biodiversity can be described as the richness and diversity of all life on earth. Biodiversity is not just about the individual species, but also about the diversity of ecosystems, species and genes and the relationship between them (Convention on Biological Diversity). Occupying 70% of the land area of the Netherlands, the agricultural landscape is the largest habitat for plants and animals. A large number of these species depend on the agricultural landscape as their prime habitat. However, in recent years species which are important for the Netherlands, like the black-tailed godwit (*Limosa limosa*), lapwing (*Vanellus vanellus*), partridge (*Perdix perdix*) and the skylark (*Alauda arvensis*), have declined. Strikingly, the most significant cause of the decline of meadow birds lies in their breeding grounds in the Netherlands, rather than elsewhere along their migratory route (Wereld Natuur Fonds, 2015; PBL, 2014). The dairy sector uses 40% of the terrestrial area of the Netherlands. As such, the sector has a large impact on the biodiversity in the agricultural landscape. Moreover, the dairy sector is one of the largest contributors to nitrogen deposition in nature areas, which is considered one of the main causes of ongoing biodiversity loss in open nature areas (Dise *et al.*, 2011).

Biodiversity is not only relevant for nature but also for agriculture, which often has specific biodiversity which contributes to ecosystem services, such as soil biota, pollinators, butterflies, etc. Therefore, decline of these species in nature also affects agriculture. Agriculture in turn can contribute to the increase and conservation of biodiversity. Agriculture has different functions of which production of food, feed and fibres and sustaining socio-economic structures and management of ecosystem services are the most important. In doing so, agriculture often makes use of and contributes to the services provided by ecosystems, such as healthy soils. In a resilient agricultural system, farming practices provide a good balance between the exploitation and use of biodiversity, ecosystem services and the natural surroundings.

In these systems, the challenge is to optimise food production while at the same time minimising impacts on the environment and the ecosystem. The notion that agriculture depends on biodiversity and that many specific species of animals and plants depend on sustainable agricultural landscapes is key in the approach of resilient agricultural systems. Both agriculture and nature can benefit from an holistic approach towards resilient systems. This approach focuses on an optimal use of agro-biodiversity and a reduction of long-term (economic and natural) risks by using ecosystem services rather than external inputs.

To promote resilience (as described in the resilience model) on dairy farms, an integrated approach is required (Buckwell *et al*., 2012). The starting point of the proposed conceptual framework is the desire to reverse the decline of biodiversity and on the other hand to better use and enhance biodiversity on the farm. Considering the importance and function (promoting resilience and reducing risks) of biodiversity on dairy farms, it is important to enhance the functional (agro) biodiversity. Functional (agro) biodiversity enhancement, however, is not enough and should be supported by landscape elements and diversity and the connections of biodiversity source areas in an area including several other farms and land uses.

We distinguish four interconnected pillars for biodiversity (Figure 1).

1. Functional (agro) biodiversity on the farm. This encompasses management of soil biodiversity, including rooting systems, grass- and cropland biodiversity, and the diversity of farm animals, the cycles of nutrients, water and energy on the farm (soil, crop, cow, business); optimised by using the functional agro-biodiversity and to serve as a basis for underground and aboveground biodiversity, water management, carbon sequestration, nutrient use, etc. The intensity of a farm largely determines whether cycles are closed at the farm level.
2. Landscape diversity at the farm: influence of the landscape elements (hedges, ditches, flower zones, trees and forests, etc.) to support the functional agro-biodiversity.
3. Specific species management (mowing, fertilisation timing, water management, etc.) at the farm for maintaining and increasing specific species (e.g. farmland/meadow birds).
4. Source areas and connection zones (landscape): management within an area (ecological corridors, exchange and connection of dry and wet zones, regional biodiversity, etc.) (Erisman *et al*., 2016).

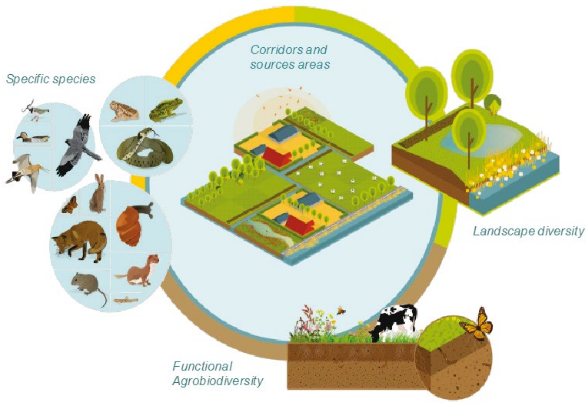

Figure 1. Four interconnected pillars for biodiversity in and around. agriculture. It starts with optimising the functional Agrobiodiversity (pillar 1), supported by landscape diversity (pillar 2), measures for maintaining specific species can be taken (pillar 3) and corridors and source areas for biodiversity (pillar 4) (Erisman *et al*., 2016).

These four interconnected pillars form the basis of the conceptual model and help the farmer to manage the farm sustainably. It builds on the force of nature which is determined by the potential of the land, region and climatic circumstances by focusing on soil, roots, grass and mineral cycles (pillar 1), supported by the region specific landscape elements (pillar 2) in connection with biodiversity sources areas, hydrological and landscape features (pillar 4). Except for the third pillar, the farmer benefits from focusing on the improvement of the other three. The third pillar is mainly for promoting the biodiversity value of agriculture and to preserve vulnerable species which depend on the agricultural land for breeding and food.

Conclusion

A paradigm shift is needed in agriculture to stop the large-scale loss of biodiversity. At present, the risks in intensive agriculture are managed by a so-called (risk) control model based on externalities, with important side effects such as risks of social costs and decreased function of natural processes. In a resilient system, risks are lower, thereby reducing costs and increasing biodiversity. Adaptive risk management is most successful when a portfolio of measures is taken. This can be achieved by focusing on four interconnected levels of biodiversity for sustainable management of ecosystem services (functional (agro) biodiversity; landscape diversity; specific species management; source areas and connection zones). The proposed conceptual framework provides a basis to derive strong indicators at the four levels and therewith forms a basis for measures of biodiversity enhancement and building farm resilience. These levels also provide the basis for a system of reward or other incentives. By managing (bio)diversity in agriculture, sustainable agriculture can contribute to reaching several Sustainable Development Goals such as clean water and climate mitigation and adaptation.

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Effect of digestate application, N fertilisation and forage species on biomass and biogas production

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Abstract

Nutrient recycling is integral to environmentally and economically efficient grassland production. Our aim was to compare production strategies with different nutrient sources when growing grass for biogas production. In a three-year field study (2013 - 2015), nutrients were applied to grass in the form of digestate from a farm-scale biogas plant, commercial N fertilisers as well as that provided by biological N fixation. The main plots were grass or mixtures of grass and clover with four different combinations of digestate and N fertilisers as sub-plots. As a three-year average, the grass-clover mixture produced 33% higher DM yields, and had similar CH_4 production potential per kg of volatile solids (VS) and 25% higher CH_4 production per hectare than grass swards. Grass DM production benefitted more from the use of 50 kg ha^{-1} of mineral N for both the first and the second cut (+57%) than from using digestate at 30 t ha^{-1} containing 92 kg N_{total} ha^{-1} (in which 66 $N_{soluble}$ ha^{-1}) for the second cut (+23%). Grass benefitted more from both types of fertilisation than the grass-clover mix (+93 vs +30%, respectively). Compared to 0 N plots, the use of digestate decreased the mean clover content less than the use of mineral N (by -20% compared to -62%). P and K balances were negative in all plots but less negative when digestate was used.

Keywords: biomass production, anaerobic digestion, methane production, nutrient cycling, clover, grass

Introduction

Nutrient recycling is integral to environmentally and economically efficient grassland production. On a dairy farm, manure is an essential part of nutrient cycling. A potential way to increase the utilisation of manure is to use it in a biogas plant where the energy content of the manure will be utilised in addition to its nutrient content. The use of grassland-based biomass from surplus areas in the biogas process increases energy production markedly. Usage of digestate from the biogas process as a fertiliser for such forage production improves the efficiency of nutrient cycling and lowers the cost of fertilisers. In addition, using legumes as a part of forage would increase the N input in the production cycle, although the methane production potential of legumes has been shown to be lower than that of grasses (Lehtomäki, 2006). The aim of our study was to compare different production strategies when producing biomass for biogas use.

Materials and methods

The study was carried out as a field experiment at the Natural Resources Institute in Maaninka, Finland (63°08' N, 27°19' E). The experimental design was a split-plot design with randomised complete blocks where the main plot was the type of species (SP) and the sub-plot was the fertilisation strategy (F) in four replicates. The species used in the grass mixture (G) were timothy (*Phleum pratense* L; cv. 'Tuure' 70%) and meadow fescue (*Festuca pratensis* Huds; cv. Ilmari, 30%), and the seeding rate was 20 kg ha^{-1}. The grass-clover mixture (GC) consisted of the same grass mixture (15 kg ha^{-1}) with the addition of red clover (*Trifolium pratense* L, cv. 'Saija') 5 kg ha^{-1}. The annual fertilisation strategies were: 1) no nitrogen (N0); 2) digestate from an anaerobic (AD) biogas process at 31 Mg ha^{-1} (D); 3) 100 kg ha^{-1} mineral N and digestate (100 N + D); and 4) 150 kg ha^{-1} mineral N and digestate (150 N + D). The plots were established in 2012 on fine sand with barley as a cover crop. During the production years, 2013-2015, the plots were harvested twice per year at the silage state of each type of species i.e. GC 6-11 days later than G. The fertilisations were divided between the first and second cuts (Table 1). Digestate was injected into the soil to a depth of 5 - 7 cm for the second cut. Dry matter yields (DM yield, kg DM ha^{-1}) and the N, P and K concentrations of the DM (g kg^{-1} DM) were determined from each cut using standard procedures. Biochemical methane potential (BMP) was determined with 30 d runs for fertilisation strategies two and four with AMTPS II (Bioprocess Control AB, Sweden) in three replicates (see Tampio *et al.*, 2014). Statistical analyses were performed using ANOVA mixed procedure of SAS 9.3. Data were analysed separately for each cut over the three production years.

Results and discussion

Over the three-year period, the DM yield of the first cut was clearly higher and it was less affected by the year (SD over years = 3.7%) than that of the second cut (SD over years = 8.4%). There was practically no difference in BMP between the cuts (Table 1). In both cuts, the effect of species and fertilisation strategy and their interaction had a significant effect on DM yield. As expected, grass benefitted more from increasing the intensity of fertilisation than clover, especially in the second cut. In general, the highest level of mineral N gave only a small response in DM production compared to a lower level of mineral N + D. As a three-year average, the grass-clover mixture produced 38% higher annual DM yields than grass. Clover and grass had similar CH_4 production potential (m^3 CH_4 t^{-1} volatile solids (VS)) without any practical differences in BMP between the cuts (Table 1). Therefore, the methane yield per hectare was highly correlated to the DM yield, reacting similarly to species composition and fertilisation strategy, with the exception of missing the SP × F interaction in the second cut. The CH_4 production of the G treatment benefitted more from 150 N (+57%) than GC (+23%; $P < 0.05$, Figure 1). Compared to 0 N

Table 1. The effect of species (Sp) composition (G = grass; GC = grass and red clover) and fertilization strategy N = mineral nitrogen; D = biogas digestate[1]) on DM yield (t DM ha^{-1} $year^{-1}$), biological methane production potential (BMP; m^3 CH_4 t^{-1} volatile solids; VS), methane yield (m^3 CH_4 ha^{-1}), and clover (RC) content in DM during experimental years 2013-2015. SEM = standard error of mean.

Sp	Fertilization		First cut				Second cut			
	First	Second	DM yield	BMP	CH_4 yield	RC	DM yield	BMP	CH4 yield	RC
			Mg ha^{-1}	m^3 CH_4 Mg^{-1} VS	m^3 CH_4 ha^{-1}	%	Mg ha^{-1}	m^3 CH_4 Mg^{-1} VS	m^3 CH_4 ha^{-1}	%
G	0 N	0 N	3.69	-	-	-	1.34	-	-	-
	0 N	D	3.68	306	1,040	-	2.50	307	690	-
	50 N	D+50 N	5.46	-	-	-	3.80	-	-	-
	100 N	D+50 N	5.69	304	1,630	-	4.03	302	1,090	-
GC	0 N	0 N	5.95	-	-	49	2.97	-	-	71
	0 N	D	6.11	292	1,610	45	3.53	291	880	45
	50 N	D+50 N	7.14	-	-	21	4.35	-	-	20
	100 N	D+50 N	7.04	291	1,900	24	4.54	285	1,170	20
SEM			0.137	4.5	39.1	5.1	0.089	5.1	37.7	3.5
Significance										
Species (Sp)			***		o	-	**			-
Fertilization (F)			***		***	***	***		***	***
Year (Y)			*			***	***			***
Sp × F			***		**	-	***			-
Y × Sp			***	*	**	-	***		***	-
Y × F							***	o	*	
Y × Sp × F			o			-	*		o	-

***($P < 0.001$), **($P < 0.01$), *($P < 0.05$), o ($P < 0.10$), [1]30 Mg ha^{-1} include 92 kg N_{total}, in which 66 $N_{soluble}$ ha^{-1}.

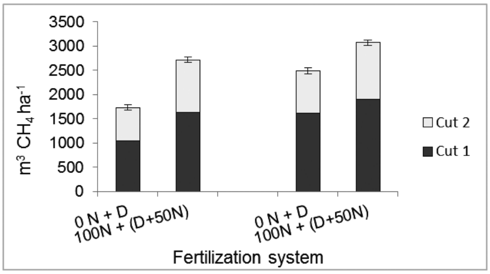

Figure 1. Average CH_4 yields for grass and grass-clover mixture when fertilized either with digestate from a biogas process (D) for the second cut, or with 100 kg ha^{-1} mineral N for the first cut and D + 50 kg ha^{-1} for the second cut. Error bars are standard error of mean (SEM).

plots, the use of digestate decreased the mean clover content less than D together with mineral N in both cuts (Table 1), and the average clover content in GC when using digestate was relatively high (45%). P and K balances were negative in all plots, but less negative when digestate was used.

Conclusions

The addition of red clover to a grass-based forage mixture increased the methane yield per hectare markedly. The clover content of the DM yield was relatively high when digestate from a biogas plant was used for the second cut but it decreased when additional mineral N was applied to increase DM yields. Using mineral N for the grass increased the methane yield of grass twice as much as grass clover.

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The multi-functionality of grasslands for delivering soil based ecosystem services

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Abstract

In this study, a land use intensity (LU_i) index was developed for evaluating the effects of management intensity on the capacity of soils to deliver different functions; grass production, water regulation, carbon (C) storage, nutrient cycling and as a home for biodiversity. On 38 grassland sites, representing the main soil types and agro-climatic regions in Ireland, the effects of fertilising, grazing and mowing intensity on soil function capacity were assessed. Increased fertiliser intensity on poorly drained soils was linked to increased soil compaction while changes in water conductivity were more apparent on well drained sites. Lower management intensity resulted in increased C sequestration capacity of these sites regardless of soil type; however, poorly drained soils were more vulnerable to compaction and C loss. Indicators of soil biological quality, such as microbial biomass C and phosphorus, were less sensitive to LU_i, however, increased mowing was found to have a negative effect on microbiological abundance and structure, due to large offtakes of C in the grass silage.Overall, the LU_i showed a high suitability to evaluate physical, C and biological response to land use intensity across grassland soils in Ireland.

Keywords: land use intensity, multifunctionality, grassland

Introduction

Grasslands represent a major land cover and global ecosystem and occupy an area of almost 40% of the earth's terrestrial surface. They make a significant contribution to global food supply and security by supporting the production of high quality livestock produce from ruminants, including milk and beef. In Ireland, over 90% of the agricultural land area consists of pasture, grass silage or hay and rough grazing, the latter accounting for approximately 11% (DAFM, 2016). Soil quality refers to the capacity of a soil to function, to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation. Agriculture today is faced with delivering increased primary productivity to meet the growing global demand for food security. At the same time, society expects that any emphasis placed on increasing food outputs is met with an equal emphasis on sustainability. The ability of grassland soils to deliver multiple soil functions simultaneously is being assessed under the SQUARE Project in Ireland. Knowledge gaps exist in relation to both the threats and benefits of soil quality. Soil structure is a key factor that supports all soil functions and it is influenced by land use and management. Competing demands for soil properties are even more imminent when considering multiple soil functions next to one another (O'Sullivan *et al.,* 2015). This paper discusses the multi-functionality of grasslands based on a national study of Irish grassland systems. A land use intensity (LU_i) index is developed to evaluate the effect of grassland soil management on a range of indicators of soil quality.

Materials and methods

A detailed on-farm survey was developed to include all common farming practices carried out in Ireland. This survey was completed on 38 farms belonging to different natural soil drainage classes, spatially distributed throughout Ireland. All of the sites were managed grassland sites, either (1) mown for silage, (2) grazed by livestock, or (3) both. These data were collected as part of a national baseline study to assess soil quality in Ireland between spring and autumn 2015. The LU_i index for Irish grassland soils was developed based on the quantitative index of Blüthgen *et al.* (2012) and included the main grassland managements information of fertilisation, mowing and grazing referred to here as sub-indices:

$LUi=Gi+Fi+Mi$

where F_i is the fertilisation level, M_i the frequency of mowing and G_i the grazing intensity, reflected by the density of livestock (livestock units days of grazing ha^{-1} $year^{-1}$) on each site *i* for a given year. Sites were clustered by drainage classes, well (n = 19) and poorly (n = 19) drained. To determine the relative impact of management across drainage classes, management intensities for *F, M* and *G,* sites were clustered into high and low based upon a normalised range of Z-score values, where an arbitrary cut-off threshold was defined as > 0 = high and < 0 = low. Management intensity was analysed across a range of key soil quality response variables including:

- Hydraulic conductivity (Ksat) and bulk density (BD) to asses soil physical quality.
- C related parameters; organic matter (OM %), soil organic C (SOC%), dissolved C (DOC) were analysed.
- Microbial C, N and phosphorus (P) indicative of biological status and nutrient cycling.

Results and discussion

Soil bulk density and Ksat were analysed as two main soil physical indicators. Across the three land use intensity sub-indices, F_i was the main sub-index for identifying changes in these parameters across the grassland sites. There were increased BD trends on more intensively managed sites and these sites had lower measured Ksat values (Figure 1ab). Increasing management pressure resulted in decreased soil porosity and water conductivity performance which can cause structural soil changes leading to a decrease of the overall physical quality. Poorly drained sites were more susceptible to compaction than well drained sites, with an observable increase in BD related to increased management intensity. However, on well drained sites, lower Ksat were observed on sites more impacted by trafficking pressure. High levels of machinery and animal traffic leading to compaction may negatively impact productivity by impeding plant root development, resulting in reduced yields.

Across all indices, C related parameter responses were best accounted for by the F_i (high versus low) index (Figure 1cde). Regardless of drainage class, lower management intensity always reflected higher C values in both the labile and stable C fractions. Importantly, this indicates that soil C is more sensitive to management intensity than to soil and site characteristics. In general, sites with a high number of fertilising operations are often coupled with intense mowing activity. Plant removal in these sites due to mowing is associated with a reduced quantity of residues present in the soil which potentially reduces the reintegration of C in the topsoil. When analysed by drainage class, the poorly drained sites, showed the highest vulnerability to increasing management intensity, with lowest concentrations of C pools in the high F_i poorly drained soils.

Management intensity showed a reduced influence on soil biological quality compared to the chemical and physical indicators. The M_i was the only sub index which showed sensitivity for microbial biomass P and C (Figure 1fg) The complete removal of plant residues from the soil through mowing activity corresponds to a lower return of C. Microbial biomass P and C concentration increase substantially when supplied with C, as C represents the food web for microrganisms. Consequently, a C limitation can result in a substantial decrease of the microbial community abundance and structure. In soils with low permeability and the tendency of flooding, the anaerobic areas increase, creating a selective pressure in microbial communities which leads to higher adaptability to changing environmental conditions.

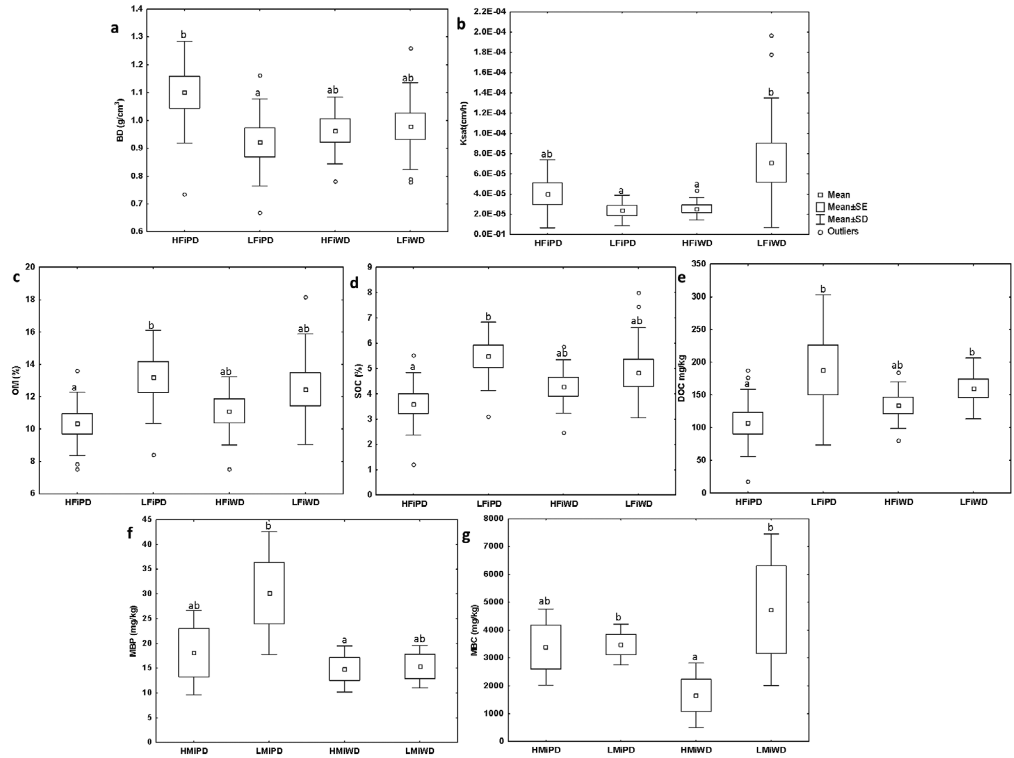

Figure 1. Physical parameter responses related to fertilising index (Fi) and drainage class for a) bulk density (BD), b) hydraulic conductivity (Ksat). Carbon response to Fi and drainage class for c) organic matter (OM), d) soil organic C (SOC) e) dissolved C (DOC). Soil biology response to mowing index (Mi) and drainage class for f) microbial P (MBP) and g) microbial C (MBC). Abbreviations e.g. HFiPD = High Fi on poorly drained soil.

Conclusion

Soil quality may be improved or maintained through management practices, such as reduced tyre and animal pressure or appropriate timing of operations. Along with reduced plant growth, soil structural quality is linked with the functional capacity of soils to provide a range of ecosystem services, including C sequestration, reduction in GHG emissions, recycling and supply of plant available nutrients, improved water quality and as a space for soil biodiversity. The LU_i developed was sufficiently sensitive as an indicator of physical, C storage and biological quality for Irish grassland soils. The heightened sensitivity of poorly drained sites to management intensity means that these soils must be particularly well managed to maintain soil quality. Overall, Irish grassland soils have good capacity to deliver multiple benefits; however, soil physical quality must be maintained or improved in order to achieve this.

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Theme 4.
Social and economic impacts of grass based ruminant production

Social and economic impacts of grass based ruminant production

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Abstract

Grass based ruminant production provides multiple benefits to farmers and to wider society. This paper addresses key economic and social factors of grass based ruminant production and illustrates them with national and regional examples from different parts of Europe. Farmers are key actors when it comes to maintaining and improving grass based production systems since they decide on the day-to-day management of the farm. The traditional farm economy model is a model where the income of farmers is a function of the price of the animal products sold, subsidies/direct payments and the associated costs of production. The multiple benefits of grass based production systems to society lead to promising new business models, where farmers are financially rewarded for their added value contributions. This is already put into practise as several societal initiatives have been started, to support rewards for ecosystem services delivered. When developing stimulating initiatives, the mind-set of the farmer should be taken into account, since this is an important influencing factor. Special attention should be paid to young farmers since they represent the next generation of farming.

Keywords: economic, grass based, mind-set, social

Introduction

The EU (28 countries) currently has a permanent grassland area of about 60 million ha (Eurostat, 2017a). Permanent and temporary grasslands represent 40% of the European total utilised agricultural area (Huyghe *et al.*, 2014) and a large acreage of these grasslands is exclusively used as ruminant feed. This asset of grasslands is extremely important for the human population since ruminants deliver food for humans as they convert the human inedible plant biomass into high quality edible proteins. Thus, by providing feed to ruminants, grasslands contribute to the feeding of mankind. Additionally, grass based ruminant production delivers a number of other services to society, like carbon (C) sequestration (e.g. Soussana *et al.*, 2010; Conant *et al.*, 2017) and biodiversity (e.g. Isselstein *et al.*, 2005). Thus far, these additional services are not usually taken into account in economic evaluations.

Grass based ruminant production systems are, however, under threat. Under climatically and topographically favourable conditions, the European grasslands area has been significantly reduced during the last 30 years (Huyghe *et al.*, 2014). According to the third report of the EU MAES initiative (Mapping of Ecosystems and Ecosystem Services), between 2006 and 2012 the main causes for this process were the conversion of grasslands into arable crops like maize (including for the production of biofuels) and permanent crops (32% of the lost area), the sprawl of urban areas, economic sites and infrastructures (30%) and the withdrawal from farming (17%) (Erhard *et al.*, 2016). In many countries, the number of dairy cows decreased in the last 30 years but the milk yield of the individual cows increased during the same period, with the cow number reductions mainly driven by the implementation of the milk quota regime. Up to 2010, the grassland area was estimated to decrease along with the cow population

(Peyraud and Peeters, 2016). Between 2010 and 2016, however, the bovine population slowly grew again by 1.4% (Eurostat, 2017b).

The improvement in individual animal milk production is achieved based on an increasing amount of concentrates and maize in the rations of cows and a declining use of herbage from grassland (e.g. Isselstein *et al*., 2005). More and more farmers have changed to all-year housing and do not provide access to grazing for their cows, e.g. only

- 42% of the German dairy cows have access to pasture (Gurrath, 2011);
- 25% of Danish dairy cows have access to pasture (Van den Pol-van Dasselaar, 2016);
- 11% of Galician dairy cows are in farms where grazing makes a significant contribution to the daily diet (Botana and Flores, personal communication).

In Galicia, for example, López-Iglesias *et al*. (2013) pointed out an increasing rate of a disappearance of farms between 1982 and 2009, with a reduction of two thirds in the number of farms in that period. Of the total land released by farms which had disappeared, more than half was abandoned or was put into non-agricultural use (mainly rapid-growing *Eucalyptus* forests).

Germany and Denmark on the one hand and Galicia on the other hand are examples of the European decrease in grass based production that is caused by two contrasting trends that are currently occurring simultaneously in Europe:

- In some regions, ruminant production systems have intensified leading to more animals per ha of grassland and less grasslands (such as Germany and Denmark).
- In other regions, grasslands have been abandoned and the percentage of the population that lives from grass based ruminant production has decreased (such as Galicia).

Marginal grasslands in several European regions tend to be abandoned, particularly in mountainous and Mediterranean areas, where they can be of crucial importance. Throughout Europe, grasslands are important for the delivery of many ecosystem services like preserving biodiversity, protecting soils against erosion, sequestering carbon, preserving the aesthetic value of cultural landscapes, the traditional cultural heritage, the attractiveness for tourists and thus, contributing to maintain the local population density. Both management intensification and abandonment have been found to be detrimental concerning biodiversity and aesthetic value (Köhler *et al*., 2005; Rey Benayas *et al*., 2007; Lindemann-Matthies *et al*., 2010; Niedrist *et al*., 2009). For this reason, ecologically, socially and economically sustainable management schemes are required, even combining different management intensities at the farm level, to ensure on the one hand a further management of grasslands by the farmers and on the other hand the continued maintenance of ecological hotspots.

This study presents key factors with respect to sustainable development of grass-based ruminant production which are illustrated with national and regional examples from different parts of Europe. The paper firstly describes the farm economy. Secondly, the importance of grass based ruminant production to society is addressed together with societal initiatives to promote grass based production systems. Farmers are key actors when it comes to maintaining and improving the important functions of grassland based ruminant production. They are key actors, because they decide on the day-to-day management of their farm. In this way, in fact, a small percentage of the population is managing benefits for the whole society. The importance of the mind-set of the farmer for management decisions is discussed. Finally, a new and emerging business model to stimulate grass based ruminant production is discussed.

Farm economy, the old business model

If farmers are expected to maintain grasslands, it is an essential condition that they will have a reasonable income. Agricultural markets are perfectly competitive and so individual farmers cannot influence the price of products sold (unless they are in a situation where they sell directly from the farm). In economic theory, the law of supply and demand is considered one of the fundamental principles governing an economy. If supply increases, prices will tend to decline, other things being equal, and vice versa. In the 'old' business model (Figure 1), which is the model that was most common throughout Europe and remains in many areas today, the income of the farmer is based on the price for animal products sold, less the costs of producing these animal products. Furthermore, subsidies may play a role. Traditionally, the CAP supported crop production more than livestock and may therefore have contributed to an historical decline in grasslands. Nowadays, in many European countries, the application of CAP results in subsidies promoting grassland based systems (at plot or at farm level). These subsidies can be a major part of the farmers' income. Where individual farmers cannot easily influence the price of animal products, a low-cost strategy (Porter, 1980) is a good choice. The assumption is that farmers strive to reach maximum profit.

There are huge differences in income on farms with grass based ruminant production. These differences are related to differences in farm characteristics in combination with differences in pedoclimatic conditions. In north western Europe, grass based ruminant production is mainly seen as an economic activity with low costs and high farm profitability (Dillon *et al.*, 2005; Peyraud *et al.*, 2010). An example of this is provided by Läpple *et al.* (2012), who showed that increased grazing and reduction in concentrate feed usage improved profitability levels on Irish dairy farms. The findings indicated that lengthening the grazing season offers a cost-saving alternative on many Irish dairy farms, which could contribute to strengthening the competitiveness of the Irish dairy sector. For example, lengthening the grazing season from the average of 233 days to 243 days would decrease the direct costs of production from 14.6 to 14.2 cents per litre for the average farm. A key factor affecting the economic sustainability of grass based ruminant production in this model is the proportion of grass in the diet. This is also illustrated in Figure 2, where a high proportion of grass in the diet of dairy cows corresponds to low total production costs.

Some regions of Europe do not have such satisfactory conditions to focus almost exclusively on grass. The various farm specific and pedoclimatic conditions that are present in Europe affect the potential for high performing grasslands and hence influence profitability. In the Alps and other marginal areas, for example, topographically unfavourable features such as slope steepness results in limits to mechanisation (Sauter and Latsch, 2011), whilst climatic limitations such as low temperatures due to increasing altitude

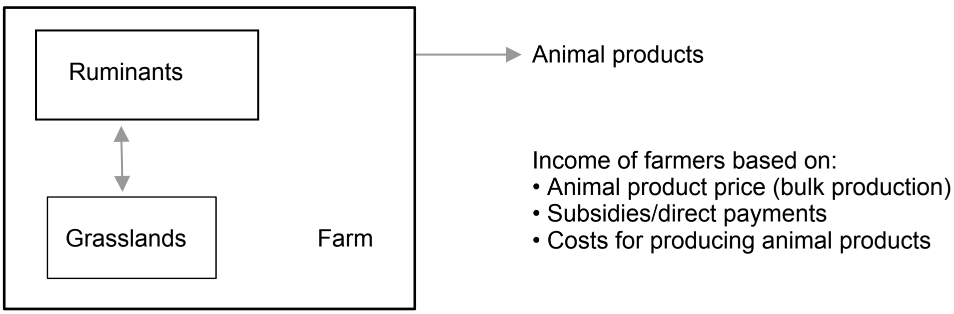

Figure 1. Grass based ruminant production in the 'old' business model; the income of farmers is based on animal products and subsidies / direct payments.

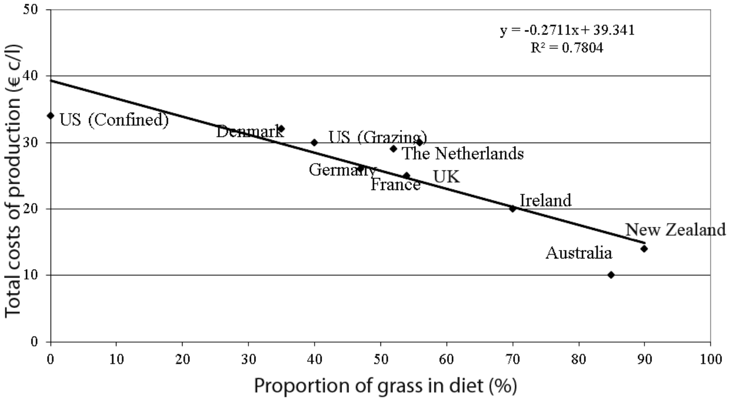

Figure 2. Relationship between proportion of grass in the diet of dairy cows and the total costs of production for different countries in the world (Dillon *et al.*, 2005).

or latitude reduce the yield potential of grassland. Both constraints result in the end in an increase in the production costs of forage (Peratoner *et al.*, 2017). Comparing the energy requirements of the livestock and the energy available in grassland forage production of two valleys of South Tyrol – a mountainous region of the Alps in north eastern Italy, an energy deficit of 46 and 47% was estimated (Tasser *et al.*, 2012).

Examples from Germany and Galicia show that the economic effect of grass based ruminant production may be restricted as the actual grass intake is relatively low:

- Botana and Flores (personal communication, 2017) showed that on average only 15% of dry matter of the total ration of lactating dairy cows came from grazed herbage.
- A first residual analysis of federal statistical data (Statistisches Bundesamt, 2014) from lower Saxony, an important milk-region in Germany, showed that only 30% of the milk produced in this region is based on grass, grass silage and hay. The vast majority of the milk is produced with concentrates and maize (Ortgies, 2014). These results are in line with an analysis of 54 German dairy farms, where cows from all-year housing and exercise pasture farms got more than 70% of their energy from maize and concentrates and farms that provided at least 0.08 ha pasture per cow got only 50% of their energy from maize and concentrates (Becker *et al.*, 2016).

So there is a tendency that, even though grass based systems are seen as low cost systems, ruminant production systems are intensifying leading to more concentrates and maize in the rations of the cows, less grass in the ration and less grazing. Furthermore, the assumed economic benefits of grass based systems are not achievable in practice in some European areas due to farm and pedoclimatic conditions or are perceived as impossible by farmers. They chose to be less grass based and transform part of their grasslands to more profitable systems. This led, for example, to grasslands in France that have been transformed into wheat and grasslands in Galicia that have been transformed into *Eucalyptus* plantations. The old business model with the underlying assumption that grass based ruminant production is profitable and will automatically be the preferred system in Europe, does therefore no longer fully work to maintain grasslands. Consequently, the question arising is whether or not this is bad and if we need a new business model or not? To answer this question, we need to look beyond the farm level and study the impact of grass based ruminant production systems for society.

New perspective: multiple benefits of grass based ruminant production systems to society

Grass based ruminant production systems provide a number of services to society (Plantureux *et al.*, 2016). The Millennium Ecosystem Assessment report (MEA, 2005) distinguished four groups of ecosystem services and grass based ruminant production contributes to all of these groups:

- provisioning services: products obtained from ecosystems, e.g. production of food;
- regulating services: benefits obtained from the regulation of ecosystem processes, e.g. control of climate and disease (grasslands contribute e.g. via C sequestration);
- cultural services: non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences, e.g. recreation and beauty of the landscape (grasslands contribute e.g. via their impact on the landscape / scenery);
- supporting services: ecosystem services that are necessary for the production of all other ecosystem services, e.g. nutrient cycles.

The ecosystem services that grasslands provide are more and more recognised by society. They are highly valued by all relevant stakeholders. A questionnaire among stakeholders (farmers, government, research, advice, education, industry, NGO's) in several European countries studying the importance of different functions of grasslands showed that some functions are especially appreciated by stakeholders. The top four were (Van den Pol-van Dasselaar *et al.*, 2014):

- grazing animals;
- animal production;
- biodiversity;
- beauty of the landscape.

The stakeholders especially value what they see when they are in the countryside: beauty of the landscape and biodiversity, both in different plant species and in ruminants that browse these species.

In Germany, it was shown that outdoor systems with grazing animals are perceived by consumers as more animal and environmentally friendly and even more traditional than housed systems (Weinrich *et al.*, 2014). Grazing is, however, not the only option with respect to grasslands that is valued by consumers. In this regard, it must be considered that topographical (i.e. steep terrain) and climatic constraints (i.e. short growing season at high altitudes), such as in the case of the Alps, may pose strong limitations to the possibility of grazing. In these areas, management by mowing (meadows) also represents a traditional grassland use that is appreciated.

Next to the positive image that grass based ruminant production delivers to society, there are also a number of ecosystem services delivered that are less visible, but vital to the whole society, like the previously mentioned C sequestration (e.g. Soussana *et al.*, 2010; Conant *et al.*, 2017). Also, grazing may have a positive effect on animal welfare, e.g. Burow *et al.* (2013) found that many daily grazing hours were more beneficial on dairy cow welfare than few daily grazing hours, and Armbrecht *et al.* (2018) found that pasture access had positive effects for claw diseases that are related to moist environments.

Exposure to certain types of agricultural landscapes, especially grasslands, could also have an important role on human health and well-being. For example, when it comes to natural amenities, access to green spaces is thought to be especially beneficial to children as children in rural areas display long term health benefits from playing outdoors (Makri and Stilianakis, 2008). There are also human health benefits to be derived from consuming products from animals raised on grass. In particular, milk from pasture-fed cows (grass or clover) has significantly higher concentrations of healthy fatty acids (Elgersma, 2015). These differences are reflected in butter produced from pasture-fed cows being superior in appearance, flavour and colour as confirmed by sensory panel data. Pasture-derived butter is also nutritionally superior for heart health with lower atherogenecity scores and containing significantly higher concentrations of CLA (c9t11), a healthy fatty acid and β-carotene which gives the butter a lovely golden colour (O'Callaghan *et al*., 2016).

All these benefits are lost when grassland is transformed into other land uses and ruminants are reared in other production systems. The decrease in the European grassland area then corresponds to a decrease in the provision of ecosystem services. In this way, the loss of grasslands and grass based ruminant production counteracts the societal good. The multiple benefits of grasslands and grass based ruminant production also offer new perspectives. As a result of rising awareness about these benefits, several societal initiatives have been developed to counteract the trend of loss of grasslands.

Societal initiatives to stimulate grass based ruminant production

European citizens react more and more to changes in their rural area. Several societal initiatives have been developed to stimulate grass based ruminant production:

- treaties (formal agreements between stakeholders);
- premiums (prizes, bonuses, or awards given as inducements);
- market concepts / differentiation of products (constructs to promote products).

These societal initiatives are illustrated by a few examples. The Netherlands provide a good example of the first two categories (treaties and premiums). In politics and society, there is a broad interest to promote farmers, whose cows have access to pasture. The visibility of ruminants, especially dairy cows, has decreased in the last decades. In the year 2001, about 90% of the Dutch dairy cows grazed on pasture, while in 2016 this percentage had decreased to 65% (CBS, 2017). Grazing has now become a real societal issue. The grazing dairy cow is seen as part of the cultural heritage of the Netherlands, and the Dutch society has expressed its concern about less grazing. As a consequence, a 'Treaty on Grazing' was initiated by a number of organisations in the full dairy chain to reverse this trend. By now, this Treaty, which aims to stabilise the percentage of farms that practise grazing, has been signed by approximately 80 organisations, including farmer organisations, industry (e.g. feed and milk robot industry), education, NGO's, government and research. As part of the Treaty, many stimulating initiatives took place. The most prominent one was the introduction of a grazing premium that is provided by the dairy industry to farmers that practise grazing for at least 120 days per year for at least six hours per day. Grazing became an issue even in parliament in 2017 when a number of political parties suggested the requirement to make grazing obligatory. Other parties were confident that the 'Treaty on Grazing' would prevent a further decrease in grazing and, as such, the Treaty prevented the obligation. At the end of 2017, it was shown that the percentage of dairy farms with grazing is increasing, which is seen as a success for the Treaty (Duurzame Zuivelketen, 2017).

The example of the Dutch 'Treaty on Grazing' with a large number of participants from different backgrounds has been followed in other countries. For example, since 2016 there is also a German 'Grazing Charta' (Deutsche Weidecharta GmbH, 2017). Recently, German dairies started to promote pasture-milk and a pasture-milk label was developed. Milk classified with this label comes from cows which graze on pasture for at least 120 days per year for at least six hours per day. Additionally, the farms must provide at least 0.2 ha grassland per cow; 0.1 ha of this grassland must be pasture for dairy cows. The farmers must provide an overview of their farm structure, the area which is supposed to be for dairy cows must not be used for heifers, calves or other animals. Actually, the farmers get 1 cent more per kg pasture milk, but this amount is expected to rise to 5 cents (Reuter and Frieler, 2017; Rohmann, 2017). The establishment of the German label was difficult, because the dairy farmers, including the grazing farmers, were sceptical about the program. They feared that the program would lead to a strong market differentiation coming with a discrimination of all-year housing farms (Kühl *et al.*, 2016).

The Netherlands and Germany are not the only countries with societal concerns about the trends towards less grasslands and less animals grazing on these grasslands. In several countries, like Spain, France and Belgium, premiums are paid to farmers in certain regions that practise grazing and / or maintain grasslands. The institutions that pay for these premiums can be very different, from consumers to industry to government. In Switzerland, for example, the government provides premiums to farmers that deliver certain ecosystem services. This is on a voluntary basis, each farmer can decide whether or not to comply with the program. In Portugal, a Carbon Fund was established, paying farmers for delivering the ecosystem service C sequestration (Teixeira *et al.*, 2015).

Another category of societal initiatives are the initiatives that relate to the quality of the animal products produced and the associated market concepts. Grass based ruminant products, especially if they are grazing based and / or of regional origin, are currently positively perceived by consumers (Bernués *et al.*, 2015) and qualitative aspects can be associated with them depending on the management practices applied (Coppa *et al.*, 2017). A differentiation of such products is necessary to ensure recognisability if a market premium is to be secured, as well as an acknowledgement and acceptance by public opinion in case public supporting measures are implemented in disadvantaged areas. Both authentication (the process verifying the characteristics of the product as complying with its description) and traceability (the ability to follow the movement of the product from the production site to the consumers) are relevant issues to this aim (Moloney *et al.*, 2014).

In conclusion, in many European countries, grass based animal products and / or ecosystem services associated with grasslands are promoted by introducing premiums and / or marketing of differentiated products. Local products are promoted as authentic and marketed as such leading to premium prices for farmers.

The farmer as a focal point: the importance of the mind-set of the farmer

When developing stimulating initiatives with respect to grasslands and grass based ruminant production, the mind-set of the farmer should be taken into account, since it is the farmer that decides on the future of grasslands. The mind-set of the farmer is important since it is known from on-farm participatory research and analysis of basic motivational drivers of European farmers, that personal values, preferences, experiences and habits of farmers are very important in management decisions (e.g. Reijs *et al.*, 2013; Baur *et al.*, 2016). When farmers and their families should be encouraged to change their system, the mind-set of the farmers must be considered. This is illustrated by some examples, which show that the mind-set of the farmer is an important influencing factor for management decisions in grass based ruminant production systems.

- A Swiss focus group analysing motivation and attitudes of farmers practicing either intensive indoor feeding (IF) or full-time grazing (FG) showed distinctive mind-set differences between the two groups concerning feeding strategies, economy and ecology (Baur *et al.*, 2010). The IF group was found to react to the increasing market pressure by means of an increase of milk production, to seek a reduction in their dependency on seasonal variation, to increase their planning capability and to perceive itself as a modern, market-oriented enterprise. The FG group put environmental sustainability, costs minimisation and considerations on common welfare in the foreground. Interestingly, it was shown that animal welfare was equally important for the two groups, although adequately fulfilling animal requirements through concentrates was the main concern of the IF group and the positive aspects of grazing on animal welfare were the main motivation of the FG group.

- Research from the Netherlands aimed to study the technical and social factors that affect the extent of grazing on commercial dairy farms (Van den Pol-van Dasselaar *et al.*, 2016) using the Theory of Planned Behaviour (Ajzen, 1991). The Theory of Planned Behaviour assumes that behaviour is affected by attitude, subjective norms, perceived behavioural control and technical possibilities. It was hypothesised that the extent of grazing is influenced by the attitude of farmers towards grazing, subjective norms about grazing, perceived behavioural control of grazing and technical possibilities for grazing. An on-line questionnaire was sent to commercial dairy farmers in the Netherlands and 212 valid responses were obtained. Results were analysed using factor analysis and multiple linear regression analysis. Including only technical factors in a model explaining the extent of grazing did not yield good results. However, combining the technical and social factors in the multiple linear regression model could account for 47% of the variation in the extent of grazing. The results imply that future work on grazing should take the mind-set of the farmer into account.
- For many farmers, an important obstacle to increase grazing is their focus on a high milk yield (Thomet *et al.*, 2011). Again, an effect of mind-set of the farmer can be found. A survey among Danish farmers showed that non-grazing farmers expected grazing to reduce their milk yield but the farmers from organic farms which offer their cows access to pasture did not associate grazing with a reduced milk yield (Kristensen *et al.*, 2010). A similar result was found in Germany, where the cows from north-west German grazing farms had less milk than the average of milk cows in this region, but the grazing farmers did not associate grazing with a reduced milk yield (Becker *et al.*, 2016). Also, Winsten *et al.* (2000) found that grazing farmers were twice as likely to increase their reliance on grazing as non-grazing farmers.

Surveys, such as the ones used in these examples, are a common method to get more information on the decision processes of dairy farmers. But the information gathered with surveys needs a critical evaluation, especially with respect to the human tendency to avoid cognitive dissonance. When confronted with an advice which implies another behaviour or management, farmers experience cognitive dissonance (Kristensen and Jakobsen, 2011). Cognitive dissonance centres around the idea that if a person knows various things that are not psychologically consistent with one another, he will, in a variety of ways, try to make them more consistent (Festinger, 1962). Cognitive dissonance can be reduced by a change of opinion, a change of behaviour or a change of perception. When a decision is made, people tend to perceive the positive aspects of their choice stronger than before, while they mainly see the negative aspects of the rejected alternative (Festinger, 1962).

A further general flaw of studies about farmers is the assumption that farmers strive to maximise profit (the old business model, Figure 1). However, they might be motivated by many other aspects, e.g. animal welfare or the recognition of other farmers (Kristensen and Jakobsen, 2011). Baur *et al.* (2016) found European farmers to be more conservative and less open to change then the general population but also identified a tendency of farmers to be less motivated by self-interest (self-enhancement) and more concerned with common welfare (self-transcendence). Though most farms are family businesses, data about technology choices on farms is routinely collected from only one person, usually a man. It remains unclear which role the decisions about farm technology play in an overall household strategy, since many studies on farms lack the data on farm women. A study among American farmers found that farm households, where technology choice is a joint decision of man and woman, were more likely to adopt intensive rotational grazing, which was at that time and place a relatively new alternative to confinement milk production. This was also more prevalent among older couples. The role of the influence of children and parents on farm decisions needs further investigation (Zepeda and Castillo, 1997).

Finally, there is often a gap between the planned intentions of farmers and actual behaviour. In general, humans tend to be too optimistic in their intentions. An example of this is provided by Hennessy *et al.*

(2016), who asked farmers about their future production levels and compared this with actual levels three years later. A large majority of the farmers tended to be too optimistic, i.e. they overestimated their future production levels.

The importance of the mind-set of the farmers implies that farmer education is very important. Farmer education is an ongoing process promoted at several levels by multiple actors. Thematically broad education is delivered from professional schools for agriculture up to the universities. As education grades are provided at specific points in time of the professional life of farmers, other ongoing training and knowledge transfer activities are needed about specific themes and can best be guaranteed by a network of extension services and innovation brokering systems interacting with the aforementioned educational and research institutions. Education provides farmers knowledge, analytical tools and technical skills that allow them to be more independent in their judgement, such as in the case of advertising and consultancy made by commercial companies. Indeed, the students of today are the farmers and farm advisors of the future, and as such, they determine the future of grass based ruminant production.

Farm economy, the new business model

Grass based ruminant production systems provide a number of relevant and highly appreciated services (Plantureux *et al*., 2016). These services provide multiple benefits to society. It is the farmer, however, that needs to maintain these benefits by maintaining the grasslands. In the past, additional services were not specifically rewarded by society. In recent years, however, a number of societal initiatives has been started to support the farmer in maintaining grasslands and grass based ruminant production systems. This has led to a new business model where farmers are rewarded either for animal production or for societal demands or for both (Figure 3).

The new business model leads to opportunities to realise the multiple benefits of grass based ruminant production systems throughout Europe. In some areas, e.g. countries with a good climate and high productivity grasslands like Ireland, grass based ruminant production will remain an economically viable activity in itself and additional rewards for ecosystem services may further increase profitability. In other areas, societal initiatives to stimulate grass based ruminant production will be necessary to maintain grasslands, e.g. premiums for delivering ecosystem services, marketing of local products, etc. The latest communication on the future of the Common Agricultural Policy also stresses the importance of supporting the public goods produced by farmers. These initiatives should be supported by innovative research and advice. Innovations in grassland management are continuously needed and are currently stimulated and promoted in regional, national and European projects. As such, they support sustainable development of grass based production systems. The European project Inno4Grass is a clear example of

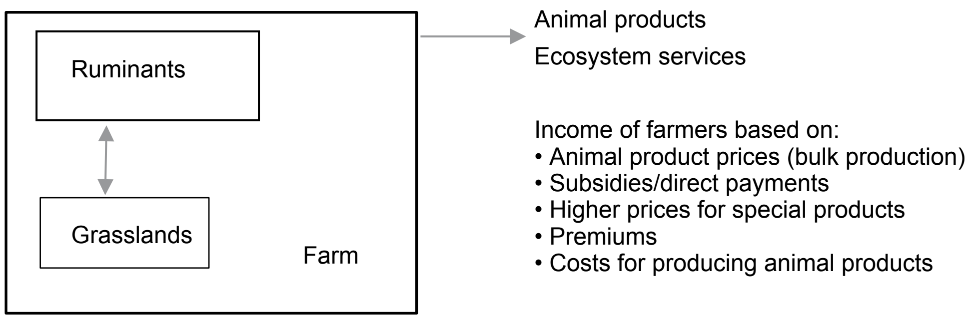

Figure 3. Grass based ruminant production in the 'new' business model; the income of farmers is based on animal products, subsidies / direct payments and rewards for additional ecosystem services.

such a project (www.inno4grass.eu). It aims to bridge the gap between practice and science communities to ensure the implementation of innovative systems on productive grasslands and to increase the profitability of European grassland farms and preserve environmental values.

Conclusion

Grass based ruminant production provides multiple benefits to farmers and to the whole of society. Supporting the continued multiple benefits of grass based production systems to society requires new business models, where farmers are rewarded for added value. Farmers are key actors when it comes to maintaining and improving grass based production systems since they decide on the day-to-day management of the farm. When promoting systems like grass based ruminant production systems, the mind-set of the farmer should play a crucial role, since it is clear from research and practice that the mind-set of the farmer is very important for day-to-day decisions about grassland management. Farmers are influenced by the human tendency to avoid cognitive dissonance, so behaviour usually changes when opinions or perceptions change. It is also clear that the often mentioned assumption that farmers strive to maximise profit is not so simple. Farmers are motivated by many other aspects, like animal welfare and the recognition of other farmers and society. To maintain grass based ruminant production, it is necessary to clearly show the importance of this production system for society to the farmers (customer perspective) and support this by valuing the products from these systems accordingly. We believe that it is the combination of these two (showing the importance and valuing this) that will shape the future and will lead to the sustainable development of grass based ruminant production. Of course this should be accompanied by clear communication. Special attention should be paid to the young farmers, since they represent the next generation of farming.

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Effect of dairy cow feeding system on milk composition and processability

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Abstract

Sixty spring-calved cows were allocated to one of three dietary treatments: grazing on perennial ryegrass pasture (GRO), grazing on perennial ryegrass plus white clover pasture (GRC), or housed indoors and offered total mixed ration (TMR). Milk from each treatment was collected on six occasions during mid-lactation (17 June and 22 September). The milks from the herds on the GRO, GRC and TMR feeding systems were denoted GRO, GRC and TMR milk, respectively. Relative to TMR milk, GRO milk had higher mean concentrations of total protein, true protein and casein, a higher proportion of α_{s2}-casein, and enhanced rennet gelation. The GRC milk was intermediate to GRO and TMR milk for most parameters. Feeding system did not affect the mean levels of non-protein nitrogen (NPN), urea N, ionic calcium or heat stability.

Keywords: pasture grass, total mixed ration, milk composition, rennet gelation, heat stability

Introduction

The composition of cow's milk is affected by several factors including stage of lactation, diet/nutrient intake and calving pattern. The predominant feeding systems for dairy cows are: grazing on perennial ryegrass (*Lolium perenne* L.) only (GRO), grazing on perennial ryegrass and white clover (*Trifolium repens* L.) (GRC), and housed indoors offered total mixed ration (TMR). White clover is frequently used as adjunct forage to grass because of its high nutritive value and nitrogen fixing ability. A number of studies have compared pasture grazing and TMR feeding for their effects on milk yield, gross composition and profiles of fatty acids and minerals (Auldist *et al.*, 2000; Gulati *et al.*, 2017; O'Callaghan *et al.*, 2016). The current study compared milk from dairy cows fed on GRO, GRC or TMR for protein profile, calcium ion content, rennet gelation properties and heat stability of milk during mid-lactation.

Materials and methods

Sixty spring-calving dairy cows from the Teagasc Moorepark herd with a mean calving date of 19 February 2015 were allocated to three different feeding systems: GRO, GRC, or TMR. The herds were each comprised of 20 cows and were balanced for breed (16 Holstein-Friesian + 4 Holstein-Friesian × Jersey), lactation number, calving date and pre-experimental milk yield and milk solids yield. The feeding systems were previously described in detail (O'Callaghan *et al.*, 2016; Gulati *et al.*, 2017). The daily feed allowance for the GRO, GRC and TMR herds was 18, 18 and 22.6 kg dry matter per cow, respectively. Bulk milk samples from each herd were collected on six different occasions in mid lactation (from 17 June to 22 September). Milk was skimmed to < 0.1% fat, and analysed, as described by Lin *et al.* (2017, 2018) for concentrations of total protein, true protein, casein, whey protein, non-protein nitrogen (NPN), urea, proportions of individual caseins and whey proteins, non-sedimentable casein, pH, ionic calcium (Ca^{2+}), rennet gelation properties at 31 °C and pH 6.55, and heat coagulation time at 140 °C (HCT) at natural pH and over the pH range 6.2 - 7.2. Data were analysed by one way analysis of variance (ANOVA) using the general linear model (GLM) procedure of SAS 9.3 (SAS Institute, 2011).

Tukey's multiple-comparison test was used for paired comparison of treatment means and the level of significance was determined at $P < 0.05$.

Results and discussion

The results (Table 1) showed that the mean concentrations of total protein, true protein and casein in the GRO milk were higher than those of the GRC or TMR milks ($P < 0.05$). Feeding system did not affect the mean concentrations of whey protein, NPN, urea, non-sedimentable casein or (Ca^{2+}), the proportions of α_{s1}-, β- and κ-caseins, or the ratio of α-La to βLg ($P > 0.05$). However, the proportion of α_{s2}-casein, which accounts for ~11-13% of total casein, was highest for GRC milk ($P < 0.05$).

The results concur with those of Auldist *et al.* (2000) who found that the concentrations of total protein and casein in milk from cows grazed on pasture during early to mid-lactation (September – April) were significantly higher than those of cows fed on total mixed ration. The absence of an effect of feeding system on the proportions of individual caseins or the ratio of α-La to β-Lg is consistent with the results of Mackle *et al.* (1999), and suggests that changes in nutrition have little impact on the relative proportions of the different caseins or whey proteins.

Table 1. Effect of dairy cow feeding system on the characteristics of mid-lactation milk.[1]

Item	Feeding system		
	GRO	GRC	TMR
Nitrogen fractions[2]			
Total protein (%, w/w)	$3.93^a \pm 0.38$	$3.74^b \pm 0.37$	$3.63^b \pm 0.30$
True protein (%, w/w)	$3.67^a \pm 0.39$	$3.48^b \pm 0.36$	$3.40^b \pm 0.29$
Casein (%, w/w)	$3.04^a \pm 0.33$	$2.90^b \pm 0.31$	$2.79^b \pm 0.25$
Non-sedimentable casein (% total casein)	$3.71^a \pm 3.14$	$6.20^a \pm 3.94$	$3.66^a \pm 2.40$
Whey protein (%, w/w)	$0.67^a \pm 0.10$	$0.61^a \pm 0.08$	$0.60^a \pm 0.07$
NPN (% TN)	$6.52^a \pm 1.17$	$7.05^a \pm 0.84$	$6.38^a \pm 0.66$
Urea (mg 100 ml^{-1})	$29.4^a \pm 8.2$	$33.0^a \pm 7.4$	$29.5^a \pm 4.5$
Individual caseins (% total casein)			
α_{s1}-casein	$38.9^a \pm 2.5$	$37.8^a \pm 2.1$	$39.6^a \pm 1.9$
α_{s2}-casein	$12.2^b \pm 0.9$	$13.1^a \pm 1.4$	$11.3^c \pm 1.2$
β-casein	$34.2^a \pm 2.6$	$34.4^a \pm 1.9$	$35.5^a \pm 1.6$
κ-casein	$14.8^a \pm 1.4$	$14.8^a \pm 1.3$	$13.7^a \pm 2.8$
Whey protein			
α-La:β-Lg (-)	$0.20^a \pm 0.03$	$0.23^a \pm 0.05$	$0.23^a \pm 0.02$
Biochemical characteristics			
pH	$6.68^a \pm 0.06$	$6.67^a \pm 0.03$	$6.67^a \pm 0.04$
Ionic calcium [Ca^{2+}] (mg 100/ml)	$11.7^a \pm 1.4$	$12.5^a \pm 1.5$	$11.5^a \pm 1.2$
Rennet gelation[3]			
GFR_{max} (Pa min^{-1})	$5.60^a \pm 1.27$	$4.86^{ab} \pm 0.82$	$4.75^b \pm 0.90$
G'_{40} (Pa)	$117^a \pm 24.6$	$99^{ab} \pm 16.5$	$95^b \pm 21.9$

[1] Bulk milk was collected on six different occasions during mid-lactation (17 June - 22 September 2015) from each of three dairy herds allocated to different feeding systems: grazing on perennial ryegrass (GRO); grazing on perennial ryegrass and white clover (GRC), or housed indoors and offered total mixed ration (TMR).

[2] Nitrogen fractions: NPN (%TN), non-protein nitrogen (% total nitrogen).

[3] Rennet gelation parameters: GFR_{max}, maximum gel firming rate; G'_{40}, storage modulus at 40 min.

[a,b,c] Values within a row relating to GRO, GRC or TMR and not sharing a common lower-case superscripted letter (a, b, c) differ significantly ($P < 0.05$) for the effect of feeding system.

Compared to TMR milk, GRO milk had stronger rennet gelation characteristics, as evidenced by the higher mean values of maximum gel firming rate (GFR_{max}) and firmness at 40 min (G'_{40}) ($P < 0.05$). The enhanced gelation of the GRO milk was consistent with its higher concentration of casein, which constitutes the para-casein gel network of the gel. Feeding system did not affect heat stability (data not shown).

Conclusion

Mid-lactation milk from spring-calved cows fed on grass had higher concentrations of protein and casein and stronger rennet gelation properties compared to milk from cows offered total milk ration. Feeding system did not affect the mean concentration of ionic calcium, proportions of non-protein nitrogen, α_{s1}-, β- or κ-casein, or the ratio of α-Lac-to-β-Lg. The higher protein content of GRO milk may be of interest to the consumer and to cheese manufacturers.

Acknowledgements

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Fatty acids and lipo-soluble antioxidants in milk from dairy farms in the Atlantic area of Spain

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Abstract

The objective of this work is to characterise the fatty acids (FA) profile and the lipo-soluble antioxidants (AO) contents in dairy cows milk from farms which followed typical feeding systems of Galician dairy region (NW Spain), mainly based on fresh and/or conserved pastures and maize silage. Thirty-seven representative farms were sampled five times between October 2013 and September 2014. A feed survey was made and samples of feed ingredients and bulk tank milks were taken. A total of 178 bulk tank milk samples of known dietary provenance were analysed for FA and AO by chromatography methods. Milk samples were allocated into five different groups by clustering techniques based on the composition of diets. A higher content of the total polyunsaturated FA (PUFA), in alpha-linolenic (C18:3n3), vaccenic (C18:1-*t*11) and conjugated linoleic (CLA-*c*9*t*11) acids and a lower omega-6/omega-3 FA ratio were found in milk samples from fresh grass based diets compared with that of maize silage diets. Milk from fresh grass diets showed the highest concentration in Lutein, all-*trans*-β-carotene and α-tocopherol, confirming that dairy milk from fresh-pastures feeding systems has a significant better fit with the actual human health requirements of consumers.

Keywords: dairy cow, milk, fatty acids, carotenoids, vitamins

Introduction

Dairy products are an important source for many vital nutrients including high quality protein, energy, and many essential minerals and vitamins, being included in recommendations for a healthy, well-balanced diet by public health organisations around the world (Rice *et al.*, 2013). Dairy cow feeding has a greater influence on milk composition than other physiological (e.g. breed, lactation stage, sanitary status) or ambient (e.g. season of the year) factors (Givens and Shingfield, 2006). A diversity of authors have described the effect of feeding regime on the dairy milk FA and AO composition. For example, Dewhurst *et al.* (2006) reported that higher proportions of fresh grass or grass silage in diet improved the milk FA profile by increasing the levels of poly-unsaturated FA (PUFA) regarded as having a positive effect on human health. Similarly, higher levels of β-carotene, xanthophylls and tocopherols are normally found when cows are fed on pasture (Jensen *et al.*, 1999). The objective of this paper was to characterise the presence of both FA and AO in milk from Galician dairy farms of known dietary provenance.

Materials and methods

A sample of 37 dairy farms was chosen as representative of the most common feeding systems in the Atlantic humid-temperate dairy production area of Galicia. Each farm was visited five times between October 2013 and September 2014 in order to establish the diet composition offered to dairy herds and to take samples of feed ingredients and bulk tank milks. Milk samples were immediately frozen (-20 °C) until posterior chromatographic analysis (FID-GC for FA and HPLC for AO), following the routines established by the official professional laboratory of milk analysis of the region (Laboratorio Interprofesional Galego de Análise do Leite, LIGAL). A total of 178 valid observations were available, of which FA and AO composition, as well as diet composition, was known. Milk samples were allocated into four groups identified previously by cluster analysis performed on the composition of the diets. An

ANOVA analysis was performed on FA and AO milk content using the group (fixed effect) as the class variable. Data were analysed using SAS package (SAS Institute, 2009).

Results and discussion

Diets were grouped based on the dry matter contribution of each particular ingredient to the total DM fed to cows. Four groups, regarded as typical diets for dairy cows in the area of study, were identified based on the predominant forage of the ration (FG: fresh grass, GS: grass silage; GS-GM: grass and maize silages and MS: maize silage). The composition of fresh herbage, grass silage, maize silage and concentrates for the four groups were (in g kg^{-1} total DM) as follows: 482, 137, 88 and 228 for FG, 86, 401, 86 and 350 for GS, 5, 285, 318 and 369 for GS-MS and 0, 63, 478, 75 and 384 for MS).

Table 1 shows that FG and GS, grass-based diets, indicated significantly higher values of total PUFA compared with GS-MS and MS diets with higher levels of maize (40.6 and 40.8 vs 34.6 and 34.7 g kg^{-1}). The presence of individual PUFA with known bioactive properties was higher in the milk samples from grass-based diets, and particularly for the fresh-herbage diets, compared with the maize-silage diets (average values of 16.3, 13.8, 8.9 and 6.6 g kg^{-1} for C18:1*t*11, 8.9, 8.0, 5.6 and 4.7 g kg^{-1} for CLA *c*9-*t*11 and 6.3, 5.2, 3.2 and 2.7 g kg^{-1} for C18:3n, FG, GS, GS-GM and MS diets, respectively) which confirms the results found by other authors (e.g. Dhiman *et al.*, 2005). Omega-6 to omega-3 ratio was significantly lower in FG and GS diets (2.61 and 3.5 respectively) compared with a value of 4.3 for the maize diets, whilst the ratio between the isomers *t*11 and *t*10 of the C18:1 followed an inverse pattern.

Significant differences were found for beta-carotene, lutein and vitamins A (retinol) and E (alpha-tocopherol) in milk, being higher in FG diet (103.8, 12.7 and 1104.3 μg l^{-1} milk, respectively) compared with silage diets (Table 2). Amongst these, the milk from maize silage based diets showed the lowest concentrations of the aforementioned AO. These results agree with a study made in 204 farms in France by Agabriel *et al.* (2007), in which it was shown that milk from cows that consume fresh grass was richer in beta-carotene, lutein and vitamin E, compared to milk from maize silage diets.

Table 1. Effect of diet type on fatty acid composition of bulk tank milks.

	FG	GS	GS-MS	MS	*P*
n	33	85	40	20	
FA profile (g kg^{-1} TFA)					
SFA	684.7 ^{bc}	680.3 ^{c}	700.5 ^{a}	697.3 ^{ab}	**
MUFA	267.7 ^{ab}	272.0 ^{a}	258.6 ^{b}	261.5 ^{ab}	*
PUFA	40.6 ^{a}	40.8 ^{a}	34.6 ^{b}	34.7 ^{b}	***
C18:1 *t*11	16.3 ^{a}	13.8 ^{b}	8.9 ^{c}	6.6 ^{d}	***
CLA *c*9-*t*11	8.9 ^{a}	8.0 ^{a}	5.6 ^{b}	4.7 ^{b}	***
C18:3 n3	6.3 ^{a}	5.2 ^{b}	3.2 ^{c}	2.7 ^{c}	***
FA ratios					
ω6 / ω3†	2.6 ^{c}	3.5 ^{b}	4.3 ^{a}	4.3 ^{a}	***
*t*11 / *t*10 C18:1††	6.4 ^{a}	4.4 ^{b}	3.0 ^{c}	1.4 ^{d}	***

[1] FG: Fresh grass; GS: Grass silage; GS-MS: Grass and maize silage; MS: Maize silage; n: number of observations; TFA: total fatty acids; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; †: Total omega-6 / omega-3 FA ratio; †† C18:1- *t*11 / C18:1- *t*10 FA ratio; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Table 2. Effect of diet type on the concentration of vitamins A and E, xanthophylls and carotene in bulk tank milks.[1]

	FG	GS	GS-MS	MS	*P*
n	33	85	40	20	
Vitamins (μg l^{-1} milk)					
Vit. A (retinol)	457.5 [a]	496.3 [a]	495.1 [a]	332.3 [b]	***
Vit. E (alpha-tocopherol)	1104.3 [a]	846.9 [b]	752.6 [bc]	661.1 [c]	***
Vit. E (ganma-tocopherol)	34.6 [c]	44.2 [b]	49.8 [b]	61.7 [a]	***
Xanthophylls (μg l^{-1} milk)					
Lutein	12.7 [a]	8.2 [b]	7.9 [b]	5.9 [b]	***
Zeaxanthin	1.8 [a]	1.1 [b]	1.1 [b]	0.8 [b]	***
β Cryptoxanthin	1.7 [a]	1.2 [b]	0.9 [b]	1.3 [ab]	**
Carotene (μg l^{-1} milk)					
(All-t-β+ 9-c-β) Carotene	103.8 [a]	82.2 [b]	62.2 [c]	50.9 [c]	***
13-*cis*-β-Carotene	5.1 [a]	3.6 [ab]	2.4 [b]	3.2 [b]	**

[1] FG: Fresh grass; GS: Grass silage; GS-MS: Grass and maize silage; MS: Maize silage; n: number of observations; $*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

Conclusion

The type of diet significantly influenced milk composition, modifying strongly its FA profile and AO content. Milk from grass predominant diets, especially that based on fresh grass showed a better FA profile and higher lipo-soluble AO concentrations, indicating a more adequate fit with the actual requirements for a healthy human diet.

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Effects of grassland extensification on yield, forage quality and floristic diversity

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Abstract

Austrian farmers taking part in Agri-environmental programmes are obliged to reduce cutting frequency and fertiliser input on 5% of their total grassland area to improve biodiversity. Typically cultivated grasslands (three-cut regime + 150 kg N ha^{-1} and four-cut regime + 200 kg N ha^{-1}) were split up into subsets: a) unmodified as reference, b) two cuts + consistent fertilisation, c) two cuts + reduced fertilisation and d) two cuts + zero fertilisation, to find out how yield, forage quality and botanical parameters were affected by various management regulations. High fertiliser rates, combined with low cutting frequencies, resulted in high yields but accelerated plant maturation and poor forage quality. The proportion of valuable plants for insects decreased in the two-cut regime with consistent fertilisation and increased the most in the unfertilised two-cut regime plots during the observation period from 2010 to 2013. Unmodified reference plots showed a higher proportion of pollinator plants in the year 2013 compared to 2010 as well, which indicates a good environmental condition of such practice-relevant management systems.

Keywords: grassland, management intensity, forage quality, floristic diversity, pollination

Introduction

Intensification during the last decades has endangered species-rich grasslands which are characterising the small scaled agricultural landscape in less favoured regions in Austria. To counteract the loss of biodiversity, farmers joining the Austrian Agri-environmental programme must implement an environmentally friendly and biodiversity-promoting management on 5% of their total grassland (BMLFUW, 2015). The aim of the present study is to investigate how yield, forage quality, floristic diversity and pollination service are affected by these restrictions.

Materials and methods

Field trials were established at three different sites in Austria (Table 1) in 1999 and used for a previous fertilisation experiment until 2009. The sward was established with a seed mixture containing *Trifolium repens, Lotus corniculatus, Lolium perenne, Dactylis glomerata, Phleum pratense, Arrhenatherum elatius, Festuca pratensis, Festuca rubra, Poa pratensis* and *Trisetum flavescens*. In all sites, a three-cut and a four-cut regime was combined with either NPK, slurry or dung + liquid manure fertilisation, representing a wide range of grassland types at the end of the first decennial period in Austria. The nitrogen content of the organic fertiliser was calculated according to the EU nitrate directive less barn and storage losses. In 2010, the previous fourfold replicated, randomised block design was modified relating to cutting frequency (c) and fertilisation level (N), without changing the fertiliser type. One replicate block (three cuts and 150 kg N ha^{-1} respectively four cuts and 200 kg N ha^{-1}) was managed unmodified and used as a reference (3c150N, 4c200N), whereas in the second replicate block the number of cuts per year were reduced to two, without changing the level of nitrogen fertilisation (2c150N, 2c200N). In the third replicate block, cutting frequency was also reduced to two cuts per year and the fertilisation level lowered to 90 kg N ha^{-1} (2c90N), whereas in the fourth replicate block the reduction to two cuts per year was combined with zero fertilisation (2c0N). Forage samples were dried in hot-air cabinet at 60 °C, milled in a Cyclotech mill to

Table 1. Location, altitude and climatic conditions of the experimental sites.

Site name	Co-ordinates	Altitude (m.a.s.l.)	Average annual precipitation (mm)	Annual mean air temperature (°C)
Gumpenstein	47°29'39.4"N/14°06'04.8"E	710	1,010	6.8
Winklhof	47°42'14.1"N/13°05'54.1"E	490	1,400	8.2
Kobenz	47°14'48.2"N/14°50'51.7"E	627	856	8.2

pass a 1 mm sieve and chemically analysed to determine crude protein (CP) using Dumas method. The cover of vascular plants was recorded at the end of the experiment in 2013. Finally, the 'flowering value' (Crane *et al*., 1984; MLR, 2011) of each recorded plant species indicating their importance for honey bees, wild bees and hoverflies was multiplied with the individual species proportion and summed up to calculate the 'flowering-points' per treatment. R version 3.3.1 was used for statistical analysis and multiple comparisons of means with Tukey contrasts using the 'multcomp' (Hothorn *et al*., 2006) package were applied.

Results and discussion

Cutting frequency, N-level and fertiliser type showed a significant ($P < 0.05$) impact on DM yield. The highest DM yields were observed within treatment 2c150N in the three-cut regime and treatment 2c200N in the four-cut regime (Table 2). In all treatments the NPK fertilised plots showed the highest yields. Within treatment 2c0N, plots which were fertilised with dung + liquid manure in the pre-period, achieved the best DM yields. This result can be explained due to a high proportion of organically bound N in this fertiliser type, resulting in a slower but longer lasting N-availability for plants. Crude protein (CP) content of the first cut was again significantly affected by cutting frequency, N-level and fertiliser type. Due to different length of growing periods, treatments with three and four cuts were not statistically compared with the two-cut treatments (Table 3). As expected, the unmodified reference treatments provided the highest CP content. Due to slower phenological development without any fertilisation, treatment 2c0N showed a higher CP content compared to treatment 2c90N. Treatments 2c150 and 2c200 had higher CP contents compared to the treatment 2c90N, which can be explained by the appearance of volunteers during the first growth. Concerning the type of fertiliser, there is evidence of a higher CP content in the NPK fertilised plots, influenced by the faster nutrient availability.

Due to considerable different results, floristic diversity (FD) and flowering points (FP) were evaluated seperately for each experimental site. Compared to the last botanical survey in 2005, FD increased at all evaluated sites within treatment 3c150N. Treatment 2c0N within the three-cut regime showed a significant rise of FD in Gumpenstein and Kobenz but a decrease in Winklhof. In treatment 2c200N a significant decrease of FD occurred at all sites. The same appeared for treatment 2c150N with the exception of Kobenz, where FD stagnated. The highest rise in FD (+ 21%) was observed in Kobenz

Table 2. DM yield (Mg ha^{-1} $year^{-1}$) during the observation period (average of 2010-2013).[1]

Fertiliser type - three-cut regime				Fertiliser type - four-cut regime			
Treatment	NPK	Slurry	Dung + liquid manure	Treatment	NPK	Slurry	Dung + liquid manure
3c150N	$9.42^{a\ ij}$	$8.18^{b\ i}$	$7.76^{b\ i}$	4c200N	$9.15^{a\ j}$	$8.51^{a\ j}$	$9.23^{a\ i}$
2c150N	$9.94^{a\ i}$	$8.50^{b\ i}$	$8.03^{b\ i}$	2c200N	$10.58^{a\ i}$	$9.59^{b\ i}$	$9.87^{ab\ i}$
2c90N	$8.51^{a\ j}$	$7.25^{b\ j}$	$7.50^{ab\ ij}$	2c90N	$8.45^{a\ j}$	$7.38^{b\ k}$	$7.55^{ab\ j}$
2c0N	$5.20^{b\ k}$	$5.71^{ab\ k}$	$6.59^{a\ j}$	2c0N	$5.26^{b\ k}$	$5.57^{b\ l}$	$6.80^{a\ j}$

[1] Superscript letters (abc for fertiliser type and ijkl for treatments) indicate significant differences ($P < 0.05$).

Table 3. Crude protein content (g CP kg^{-1} DM) of the first cut (average of 2010-2013).[1]

Fertiliser type - three-cut regime				Fertiliser type - four-cut regime			
Treatment	**NPK**	**Slurry**	**Dung + liquid manure**	**Treatment**	**NPK**	**Slurry**	**Dung + liquid manure**
3c150N	101^{a}	87^{b}	85^{b}	4c200N	140^{a}	134^{ab}	129^{b}
2c150N	$79^{a\ i}$	$71^{b\ ij}$	$67^{b\ i}$	2c200N	$79^{a\ i}$	$74^{a\ i}$	$71^{a\ i}$
2c90N	$67^{a\ j}$	$66^{a\ j}$	$69^{a\ i}$	2c90N	$64^{a\ j}$	$66^{a\ j}$	$65^{a\ i}$
2c0N	$76^{a\ i}$	$75^{a\ i}$	$74^{a\ i}$	2c0N	$73^{a\ i}$	$72^{a\ ij}$	$72^{a\ i}$

[1] Superscript letters (ab for fertiliser type and ij for treatments) indicate significant differences ($P < 0.05$).

within treatment 2c0N in the former four-cut regime. By contrast, treatment 2c200N in Gumpenstein showed the highest reduction (- 36%). In total, FD at the initial situation was lowest in Winklhof and only one of the treatments showed a significant increase there. In Gumpenstein and Kobenz, where the initial situation already provided a broader variety of plants, two of the four tested treatments performed significantly better than the references with regard to FD. At all sites with the exception of Winklhof, FP were highest within treatment 2c0N. The reference plots 3c150N and 4c200N showed, on average, the second highest FP, whereas treatments with a reduction of the cutting frequency but with consistent or reduced fertilisation level performed worst. With regard to fertiliser types, slurry and dung + liquid manure increased FP more than NPK.

Conclusion

A reduced defoliation regime combined with a lower fertilisation level is a suitable measure to increase FD and the proportion of valuable plants for insects on grassland. Poor forage qualities and lower yields, mainly influenced by the fertilisation level, are the result of low cutting frequencies. A site-adapted defoliation regime with three cuts, combined with well adapted fertilisation levels, shows a positive impact with regard to FD and the proportion of valuable plants for insects as well.

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The net contribution of ruminant production to the protein supply for humans

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Abstract

Total protein conversion efficiency of ruminant production systems is low (between 0.05 for meat and 0.25 for milk), but this calculation usually does not differentiate human-edible from human non-edible feedstuffs (e.g. grass, by-products of food and biofuels industries). To evaluate the net contribution of ruminant livestock to protein production for human consumption in France we estimated the human-edible protein Fraction (hepF) of the diets and the net protein efficiency (human-edible protein efficiency) from six contrasting feeding systems in dairy, beef cattle and sheep systems. The hepF values of diets ranged from 3% (extensive sheep production) up to 26% (intensive dairy cattle production). The net protein efficiency ranged from 0.34 (intensive sheep production) up to 2.57 for grass-based dairy cattle production with low concentrate consumption. Each type of ruminant production can produce more edible protein than they consume (net protein efficiency > 1). The use of grass and by-products are the key factors to improve the net contribution of ruminant production to protein supply for humans.

Keywords: protein efficiency, feed-food competition, dairy cattle, beef cattle, sheep, human-edible protein

Introduction

Ruminant production is perceived as less efficient and in competition with crops for the human food supply. It takes more than 3 kg of plant protein to produce one kg of milk protein and between 5 and 10 kg to produce one kg of bovine meat proteins (Peyraud and Peeters, 2016). This usual way to evaluate protein conversion efficiency does not differentiate human-edible from human non-edible feedstuffs (e.g. grass, by-products of food and biofuels industries) in livestock feeding. The feed/food competition only concerns those proteins of plant origin that are consumed by animals and that are consumable by human. The amount of edible protein of animal origin produced by kg of human-edible protein of plant origin used in animal feeding is an unbiased view of the contribution of livestock to protein production (Wilkinson, 2011; Ertl *et al.*, 2015). The aim of this work was to evaluate the potential of ruminant livestock for net production of protein for human consumption with a focus on contrasted French dairy cattle, beef cattle and sheep production systems.

Materials and methods

The total protein efficiency and the net protein efficiency at the production system level were calculated as follows:

Total protein efficiency = total protein output / total protein input

Net protein efficiency = human-edible protein output / human-edible protein input

With: output = all animal products; and input = all feeds consumed

The human-edible protein output includes all edible protein from the production system. Ninety eight percent of the milk sold by dairy cattle farms is human-edible and the edible fraction of animals (meat, edible offal and by-products) currently consumed in France represents 55, 60, 63 and 43% of total protein in slaughtered animals for dairy cow, beef cow, fattened young cattle and lamb respectively, Laisse *et al.* (2016).

The human-edible protein input includes all human-edible feed protein consumption of the production system. A table of human-edible protein fraction (hepF) of the main feedstuffs used in France was built from literature data and interviews with the food industry experts (Laisse *et al.*, 2016). For example, in the 'current situation' of food industry, hepF of wheat, maize grain, soybean meal and rapeseed or sunflower meal were estimated respectively at 66, 15, 60 and 0%. The hepF values of forages were estimated at 0%, except for maize silage which hepF was set at 10% to consider the grain fraction. A 'potential scenario' was built with increased values of hepF to take into account the progress in protein extraction from the food industry in the future (e.g. protein extraction from rapeseed meals) and the potential changes in eating habits (e.g. more consumption of wholemeal flours).

The total and the net protein efficiency were then calculated using data from real farms collected in the farm network surveys from INRA, IDELE and Chambres d'Agriculture ('Inosys-Réseaux d'Elevage'). All calculations were made at the production system level taking into account all animals and all feed consumptions. Table 1 presents the main characteristics of the production systems studied.

Results and discussion

Total protein efficiency of ruminant production systems is low and varied between 0.05 (BC1) and 0.24 (DC1) (Figure 1). The hepF of the whole diets is also low and varied between 3% (Sh2) and 26% (DC1) for the 'current scenario'. The net protein efficiency is much higher than the total protein efficiency and reached or exceeded a value of 1 for DC1 and DC2, BC2 and Sh2 (Figure 1). This means that all ruminant production systems have the potential to produce more human-edible protein than they consume and contribute positively to the production of protein for human nutrition.

Figure 1 reveals large variation in net protein efficiency within each type of ruminant production. Grass-based dairy cow systems with low consumption of concentrates (DC2) can produce 2.5 times more human-edible protein than they consume. For beef cattle systems, cow-calf fattening systems can produce as much or more human-edible protein than they consume, provided they use low amount of maize silage and soybean meal (BC2). Sheep production systems with 1 lambing year^{-1}, high consumption of grass

Table 1. Animal performances and diet composition of the livestock systems studied.

Production system characteristics				Diet composition (% of total dry matter consumed)						
Type of production		Animal productivity[1]	Concentrate consumption	Maize silage	Grass forages	Cereal grains	Cereals by-products	Soybean meal	Other meals	Other feedstuffs
Dairy cattle	DC1	8,490 l cow^{-1}	1,480 kg LU^{-1}	42.4	38.6	7.7	1.2	6.2	2.9	1.0
	DC2	5,745 l cow^{-1}	603 kg LU^{-1}	0.0	90.0	7.7	1.0	0.1	0.2	1.0
Beef cattle	BC1	400 kg LU^{-1}	776 kg LU^{-1}	7.0	73.0	4.0	4.0	8.0	2.0	2.0
	BC2	453 kg LU^{-1}	763 kg LU^{-1}	4.0	78.0	4.0	5.0	5.0	1.0	3.0
Sheep	Sh1	1.83 lamb ewe^{-1}	148 kg ewe^{-1}	0.0	87.0	5.3	3.3	1.9	0.7	1.8
	Sh2	1.51 lamb ewe^{-1}	48 kg ewe^{-1}	0.0	96.2	1.4	0.8	0.5	0.2	0.9

[1] l cow^{-1} = annual milk production per cow; kg LU^{-1} = live weight produced per livestock unit (LU), more than 90% of the live weight produced is fattened and slaughtered; lamb ewe^{-1} = ewes > 12 months.

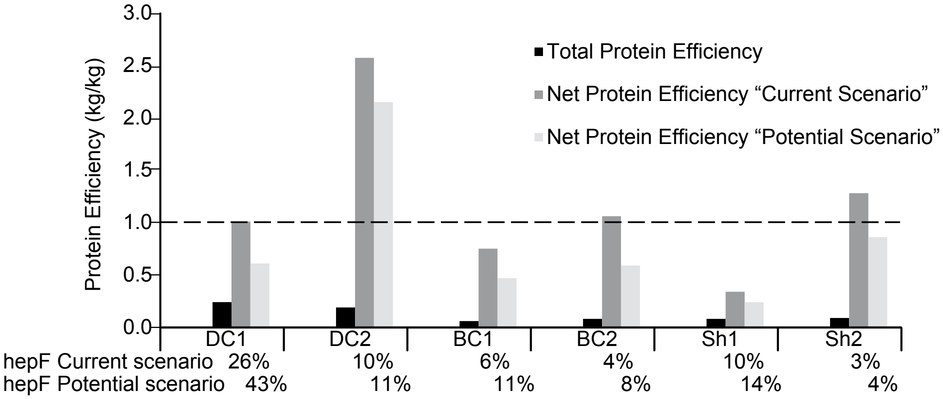

Figure 1. Total and net protein efficiency of the ruminant livestock systems described in Table 1, according to the human-edible fraction of the diet (hepF) for current and potential scenarios.

and very low consumption of concentrates (Sh2) can also be net producer of protein compared to more intensive systems with 3 lambing per 2 years and higher concentrate consumption (Sh1).

With the 'potential scenario' of protein use for food, net protein efficiency of all production systems decreases. Grass-based dairy system remains a net protein producer. This clearly shows the interest of grass and non-edible by-products to improve the net protein efficiency of ruminant production systems. By taking into account the higher nutritional value of animal proteins for humans, a net protein efficiency of 0.8 would be sufficient to at least maintain a neutral contribution of ruminant productions to the protein supply for humans (Peyraud and Peeters, 2016).

Conclusion

The calculation of net protein efficiency, taking into account the human-edible part in feed consumption, shows that dairy cattle but also beef cattle and sheep production can positively contribute to the protein supply for humans. The use of grass and non-edible by-products are the key factors to improve the net protein efficiency of ruminant productions.

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Designing economic instruments to maintain and enhance hay meadow biodiversity in south-west European mountain areas

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Abstract

Hay meadows are disappearing all over Europe, and with them, areas of high biodiversity. Recently, this process has also affected significant surfaces of mesophile hay meadows in south-west European (SW-EU) mountain areas, due to changes in land management and socio-demographic decline. Specific agri-environmental subsidies are one of the potential instruments to favour their conservation, but they are not applied to most of these territories. This study aims to analyse how current agricultural payment schemes from CAP and Rural Development Programmes (hereinafter RDP) can be used to enhance biodiversity conservation by promoting the maintenance/recovery of the traditional extensive management of mesophile hay meadows in Natura 2000 sites within SW Europe. To reach this goal, an extensive review and characterisation of economic instruments applied to the conservation of these meadows in Europe has been carried out. A clustering and comparative analysis of their main features, transfer possibilities and implementation results have been also addressed. The study proposes strategic guidelines to design and put into practice future economic measures to conserve mesophile hay meadows in different SW-EU mountain protected areas.

Keywords: mesophile hay meadows, mountains, subsidies, conservation, south-west Europe

Introduction

After centuries of extensive stock management, hay meadows are Agri-ecosystems with a high botanical and faunistic value and importance for European rural landscapes (Dengler *et al.*, 2012). Although two types of hay meadows are catalogued as natural habitat types of Community interest (6510 and 6520) according to the European Habitat Directive, their general decline (Keenleyside *et al.*, 2014) has also already reached south-west European countries (SW-EU), where traditional management still survives in mountain areas in north-west Portugal, the Cantabrian mountain range and the Pyrenees. Intensification of hay meadows, reconversion into developed parcels, grasslands, or simply, their abandonment is very quick in these areas (García Manteca *et al.*, 2017). Most of the sw-EU mountain areas where these meadows are located currently lack specific subsidies for their conservation and sustainable management, or the existing subsidies are ineffective. This study aims to analyse how current agricultural payment schemes are being applied and designed in Europe to enhance biodiversity conservation by promoting the maintenance of hay meadows, in order to propose transfer patterns to mountain mesophile hay meadows in Natura 2000 areas within SW-EU.

Materials and methods

In 2016 and 2017, subsidies from CAP, RDPs and other EU instruments to maintain/recover hay meadows and their traditional extensive management have been compiled and analysed. For SW-EU

(Spain, Portugal and France), the information was taken from the national and regional RDPs and CAP measures in the 2007-2013 and 2015-2020 programming periods. Technical documents on the application and assessment of measurements provided by governments and other territorial agents were also consulted. Information on recent initiatives of interest, related to agri-environmental subsidies to conserve hay meadows, and to European programmes such as *Results Based Agri-environmental Payments Schemes* and LIFE, was also compiled from the rest of Europe (Opermann *et al*., 2012). All the subsidies were stored in a database and a descriptive data sheet, with specific fields to characterise them, evaluate their effectiveness and transfer possibilities. Subsidies were classified into three main groups, designed to tackle the problem of hay meadows disappearance in a similar way. A descriptive statistical analysis of these aids was carried out to know their frequency of implementation, prevailing subcategories, distribution by regions, etc. Finally, virtues and problems of design and implementation were identified and the most common ones were outlined (per main group) to guide a potential transfer.

Results and discussion

Thirty subsidies applied in Europe since 2007 that contribute to hay meadows conservation were identified (Table 1). Eighty percent were channelled through the European RDPs (II Pillar CAP) and 57% applied in SW-EU (France, Spain and Portugal). In total, 63% of the payments are specifically earmarked for hay meadows and 33% represent other subsidies with positive indirect effects on hay meadows.

The three major payment schemes specifically applied to conserve hay meadows in Europe are linked to the II Pillar CAP and characterised by a natural-territorial heritage conservation approach and a flexible local-regional design to capture specific environmental problems and objectives. The measures are voluntary and applied at parcel scale throughout Agri-environment-climate measures (M10 code according to CAP nomenclature) of the RDPs. The 'classical' design (subsidies aimed at complying with commitments for the sustainable management of hay meadows) reduces control efforts by authorities and usually reaches a broad territorial scope to preserve traditional good practices and surfaces. For the measures to be effective, commitments must be verifiable and reflect good traditional extensive practices according to regional customs regarding mown and grazing. The 'results-oriented' subsidies are earmarked to environmental priority areas in order to sustain agricultural ecosystems that favour biodiversity and habitats of interest, although they generally register high costs and complex methods to assess if environmental objectives have been indeed reached. For these to be effective, both subsidy and mechanisms for results assessment (as lists of indicator species) must be defined locally and engage the key territorial operators. Finally, compensatory payments in Natura 2000 sites (M12) are applied

Table 1. European subsidies that contribute to hay meadows conservation since 2007.

		Specific/direct, aimed at:		Indirect, aimed at:	Total
		Commitments	Biodiv. results	Commitments	
II Pillar CAP (RDPs)	M10-Agri-environment-climate	6	6	7	19
	M12–Natura 2000 & WFD	2	-	-	2
	Particular programmes[2]	1	-	-	1
	M13-Areas with constraints	-	-	2	2
I Pillar CAP[1]	Coupled payments	-	-	1	1
Other	Non-EU Direct payments	-	-	1	1
	Pilot projects[3]	-	4	-	4
Total		9	10	11	30

[1] Excluding greening.

[2] G.L.A.S. (Ireland).

[3] Results Based Agri-environmental Payment Schemes (RBPAS).

when a Management Plan introduces constraints to the normal management of hay meadows, causing losses or extra costs. Outcomes indicate that the correct calculation of payments (annual sum per hectare) should contemplate costs and income losses associated with traditional extensive management, opportunity costs of maintaining the meadows (opposed to other alternatives), and 'leave space' for rewarding the environmental excellence of professional stockbreeders. Likewise, certain subsidies of I Pillar CAP (coupled payments linked to basic payment for livestock farms in mountain areas) and II Pillar (areas facing natural constraints, protection of local breeds in danger of being lost, communal mountain grasslands in extensive use, traditional irrigation systems, etc.) play indirectly an important role in hay meadows conservation. Finally, exploring changes in I Pillar is considered to be highly interesting for extensive livestock farms with a high dependence on them or located in protected areas.

Since effectiveness assessments for hay meadows conservation are not available for most of economic aids (only some French subsidies have been partially assessed before 2010), transfer guidelines are limited for the moment. Portugal and Spain lack previous experience in applying 'results-oriented' subsidies to hay meadows conservation, so pilot programmes are needed before transfer. For the 'Commitments-oriented' subsidies to be transferable to SW European mountain areas, empirical evidence previously mentioned about virtues and problems of design and implementation should be considered.

Conclusion

Thirty European subsidies applied since 2007 for the conservation of hay meadows, their natural value and traditional extensive practices have been identified and characterised. Mountain areas in Portugal, Spain and France still preserve mesophile hay meadows of an exceptional quality, but their fast disappearance requires the application of specific economic sustainability programmes whose design is based on the agri-environmental subsidies experience, aimed at complying with management commitments or at obtaining biodiversity results. Next CAP reform is a strategic opportunity to improve hay meadows maintenance support within I Pillar, especially for extensive livestock farms highly dependent on them.

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Factors associated with profitability in pasture-based systems of milk production

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Abstract

The objective of this study was to quantify the factors associated with profitability on pasture-based dairy farms using an internationally recognised representative database over an eight year period (2008 to 2015). To examine associated effects of a number of farm systems and management variables on specific performance measures, multiple regression models were developed. Factors evaluated included pasture utilisation (kg DM ha^{-1}), stocking rate (LU ha^{-1}), grazing season length, proportion of purchased feed and milk production parameters. On average, over an eight year period, each additional tonne of pasture DM utilised increased net profit by €173 on dairy farms. Conversely, a 10% increase in the proportion of purchased feed in the diet resulted in a reduction in net profit per ha of €97 and per kg of fat and protein of €0.21. Results from this study have demonstrated that the efficiency of pasture-based dairy systems is significantly associated with total pasture utilised and the proportion of pasture utilised at farm level taking cognisance of the levels of purchased feed used.

Keywords: dairy systems, pasture-based milk production

Introduction

The dynamics of global agriculture are constantly changing due to the continuous fluctuation of international food markets, coupled with the increased globalisation of agriculture, policy changes globally, greater societal expectations and environmental constraints. All these factors combined, force the requirement for resilient sustainable agricultural systems, with the highest food safety standards, capable of withstanding external and/or internal business shocks. Many studies have reported that pasture-based systems of milk production have a distinct advantage over high input systems, with grazing systems associated with greater global sustainability, increased product quality, improved animal welfare and increased labour efficiency (Dillon *et al*., 2005; Macdonald *et al*., 2008; O'Brien *et al*., 2012). There are further requirements to increase efficiency and sustainability in pasture-based systems. Increasing efficiency and profitability of a farm business requires particular focus on increasing output through increased pasture growth and utilisation (Shalloo *et al.*, 2011), with previous research reporting major potential for improvement in efficiency within pasture-based systems in Ireland (Creighton *et al.,* 2011; Kelly *et al.,* 2013).

This study quantified the association between key farm system parameters on profitability across a longitudinal dataset (8-years) of pasture-based dairy farms.

Materials and methods

The data used in this analysis originated from the Irish National Farm Survey (NFS) (Hennessy and Moran, 2014), a survey that has been conducted by Teagasc annually since 1972, and is representative of pasture-based dairy farming in Ireland. For the purpose of this study only specialised dairy farms were used in the data analysis. The analysis was conducted on NFS data from an 8-year period (2008 to 2015), containing on average 257 specialised dairy farms annually and, in total, 2,055 surveys. The analysis was conducted over this time period to test the robustness of the analysis across different years (weather variations and milk price ranges). The outputs from the survey provide a range of physical and financial performance indicators for each farm such as: farm details, stock details, product yields, sales, purchases, costs and profits including full reconciled farm management accounts. The analysis was completed by firstly undertaking a series of calculations using Microsoft Excel, before being compiled together for full statistical analysis with the SAS 9.3 statistical analysis programme (SAS Inst. Inc., Cary, NC). The analysis was completed using specifically the dairy enterprise and its associated stock numbers, land area (dairy forage ha) and financial details, etc. to ensure consistency between farms.

The profitability of the farms included in the dataset was measured on a dairy net profit basis. Factors associated with net profit per ha and per kg of fat and protein were determined using a general linear model in PROC GLM (SAS Inst. Inc., Cary, NC). Factors considered for inclusion in the model were year (2008 to 2015), region (Border, Dublin, East, Midlands, Southeast, Southwest, South and West), soil type (Group 1, 2 and 3), milk recording (Yes or No), discussion group membership (Yes or No) and covariates pasture utilisation (kg DM ha^{-1}), stocking rate (livestock units (LU) ha^{-1}), grazing season length, breeding season length, herd size, dairy farm size (ha), farmer age, proportion of purchased feed, protein %, fat %, kg of fat and protein per cow and per ha. Soil groups 1, 2 and 3 were representative of high, medium and low quality soil types respectively. The multiple regression models were built using a stepwise forward-backward regression methodology; the significance threshold for entry and exit of variables into/from the model was set at 5%.

Results and discussion

Over the eight years, the dataset indicates a general trend of increased cow numbers and rising stocking rates over the time period. The proportion of purchased feed used on farms remained relatively static, with an average of 22% of each farm's energy requirement purchased annually in the form of concentrate (19%) and other forages (3%), on a DM basis. Meanwhile, whole farm pasture utilisation per ha per year varied from a mean of 6,728 kg DM per ha in 2008 to 7,796 kg DM per ha in 2015, which coincides with a general rising trend in milk fat %, protein %, stocking rate and milk output per ha. As expected, net profit figures varied throughout the study period in accordance with the significant milk price fluctuations observed at farm level. The statistical model investigated the factors associated with the different variables net profit per ha and per kg of fat and protein on pasture-based dairy farms. Net profit per ha and per kg of fat and protein were significantly associated with a range of fixed, structural and technical management effects that were under varying levels of farmer control. Pasture utilisation (P < 0.001), grazing season length (P < 0.001) and kg of fat and protein per cow (P < 0.001) were significantly positively associated with both dependent variables, while proportion of purchased feed (P < 0.001) and dairy farm size (P < 0.01) were negatively associated. Longer grazing season lengths and increased pasture utilisation were significantly associated with an increase in net profit per ha of €1.85 per day (s.e.0.45) and €173 per tonne of DM (s.e.6.34), respectively. This further emphasises previous detailed research on the increases in profitability gained through extended grazing season lengths (Kennedy *et al.*, 2005; Kelly *et al.*, 2012; Läpple *et al.*, 2012). Increasing the proportion of purchased feed on farm by 10% was associated with a reduction in net profit per ha of €97 (s.e.13.7) and net profit per kg of fat and protein of €0.21 (s.e.0.02). The use of purchased feed and its association with profitability demonstrated in this study is in agreement with previous research which reported that increasing the proportion of purchased feed in the diet increases a wide range of production costs and consequentially reduces farm net profit (Ramsbottom *et al.,* 2015). An increase in milk fat and protein production per cow was associated with an increase in farm profitability per ha, but only when increases were gained from increasing the proportion of grazed grass in the system.

Conclusion

Using a relatively large dataset, across an eight year period (2008 to 2015), this analysis provides a strong argument for the benefits of focusing on a number of key performance metrics within pasture-based systems. Pasture utilisation per ha has been demonstrated to be a crucial measurement of farm efficiency and a key performance indicator for benchmarking and determining proficiency levels within and across farms and across years. Other key performance indicators associated with maximising efficiency and profitability at farm level include grazing season length, proportion of purchased feed, milk fat and protein production and milk constituents. Efficient pasture-based milk production will be achieved by appropriately setting farm stocking rates to the farm pasture growth and utilisation capabilities, while maintaining high levels of pasture management and stringent cost control.

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Sulphur improves feed quality in intensively managed grassland in Germany

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Abstract

Recent studies indicate a demand for sulphur in intensively managed grasslands to optimise DM yield and quality. In this study, DM yield and quality responses to sulphur application were measured in field trials with perennial ryegrass (*Lolium perenne L.*) at three different sites in Germany. Responses were evaluated at two nitrogen fertilisation levels of 320 and 393 kg N ha^{-1}. The field trials were conducted in Rockstedt (humic sand), Kleve (clay loam), and Moosburg (loess soil), with optimum P and K application in spring and without application of organic fertiliser. The effect of sulphur application on DM yield, nutrient uptake and feed quality (protein, fibre, sugar, energy, ADF, NDF) was determined. A site-dependent sulphur effect on DM yield was found and the sulphur content of the grass increased throughout the whole season on all sites in 2016 with sulphur application. A positive impact on protein and energy content was observed for all sites, leading to a total energy and protein yield gain. Effects on DM yield and quality were more pronounced at the higher N levels. These results show the importance of sulphur application in intensively managed grassland for production of high-quality feed.

Keywords: *Lolium perenne L.*, sulphur, DM yield, feed quality

Introduction

Sulphur is essential input for optimum yield and quality in intensive grass production; it is part of amino acids and plays a role in the formation of protein structure. There is a clear link between nitrogen metabolism and sulphur in plants. Sulphur becomes even more important under intensive production with high nitrogen input. Sulphur also affects grass quality by improving protein and energy content. Many trials on the application of sulphur to grassland have been conducted, mostly focusing on DM yield and nutrient contents. Even though yield responses were not always detected, grassland field trials reveal the best response to sulphur at nitrogen rates required for optimum dry matter yield. Positive sulphur responses on feed quality have been found in pot trials. Soluble sugar contents were increased when sulphur was applied in combination with a high N supply in pot trials conducted with ryegrass (Bolton, 1976).

Materials and methods

This study investigates the comparison of straight N application versus combined application of nitrogen and sulphur at different grassland sites in Germany. Fully randomised plot trials were installed in 2015 or 2016 on established, intensively managed grassland sites in Germany. These were located at different regions and soil types. Average annual temperature was between 7.7 and 10.0 °C, and average annual rainfall was in the range of 700-800 mm (Table 1).

Next to a control treatment which received no N and S applications, a 2-factorial trial with N Rate × S application was installed. Nitrogen application levels of 320 and 393 kg N ha^{-1}, representing 100 and 120% of recommended N rate were applied, either as calcium ammonium nitrate (CAN, 27%N), or as YaraBela Sulfan (24%N, 6%S). Fertiliser N recommendation was based on a yield objective of 13 t DM ha^{-1} (Berendonk, 2009). Base dressing with P and K according to soil test results was applied on all sites. CAN and YaraBela Sulfan were applied at rates of 100, 80, 60, 40, 40 kg N ha^{-1} to cuts 1 to 5, respectively, at 100% recommended rate, and accordingly at higher rates 120% recommended rate. Grass

Table 1. Location, soil and climatic properties of the trial sites.

Site	Rockstedt	Kleve	Moosburg
Location	51° 17′ 5.541″ N 10° 45′ 44.675″ E	51° 47′ 9.276″ N 6° 10′ 6.996″ E	48° 26′ 36.816″ N 11° 54′ 22.824″ E
Soil type	Sandy soil	Clay loam,	Loess soil
Soil pH	5.0	5.9	n.a.
P_{CAL}; g P kg^{-1} soil	18 (low)	57 (adequate)	70 (adequate)
K_{CAL}; g K kg^{-1} soil	25 (low)	58 (adequate)	133 (adequate)
Avg. annual rainfall; mm	780	712	814
Avg. temperature; °C	8.5	10.0	7.7

was harvested five times during the growing season. In 2016, plant tissue has been analysed for nitrogen and sulphur and feed quality parameters (crude protein, sugar, fibre, NDF, ADF) were determined by NIRS; energy content was estimated according to DLG, 2013.

Results and discussion

Dry matter yield was significantly increased over the unfertilised control treatment at all sites. Over all sites, the treatments receiving 120% of recommended N rate showed a further yield increase compared to those at 100% of recommended N rate. Sulphur improved DM yield at both N levels. Data from 2015 is only available for Rockstedt and Kleve, sulphur application resulted in a DM yield increase of 5.6% on average across the sites and N levels. Energy content was increased and protein and fibre content were slightly reduced in that year. In 2016, the sites differed in their response towards both factors. On the sandy soil in Rockstedt there was a significant yield response to S, but no N was found, whereas on the other soils the response to the increased N rate was statistically significant, but not the S response. A consistent, positive yield effect of sulphur application was found on all sites, despite a high overall S supply in Moosburg. S contents were in an adequate range in all treatments, indicating that the S effect was not based on mitigation of S deficiency. Nitrogen, as well as sulphur application, had a non-significant but consistent impact on nutrient contents and feed quality parameters: increases in nitrogen application led to increases in crude protein and energy content, whereas the fructan and NDF content decreased. Sulphur application resulted in increased contents of sugar, fructan and energy, NDF was reduced with sulphur application. The effect of sulphur on crude protein content was inconsistent over the sites. Interactions were found between nitrogen and sulphur treatments in this trial series, DM yield and energy content were increased with higher N rate and the sulphur effect was more pronounced at high nitrogen levels resulting in maximum DM yield and feed quality at 120% of N application in combination with sulphur. DM yield and feed quality results from 2016 are shown in Table 2, given as total or average DM yield of all harvests, respectively.

Higher contents of sugar and fructan after sulphur application were assessed in this trial series. Both belong to the group of water-soluble carbohydrates in plants. They are quickly released from the feed within the rumen and provide energy to ruminal microbes and contribute to high feed value silage. Depending on Site and N application rate, the NEL content of grass fertilised with sulphur was increased on average in all harvests up to 0.28 MJ kg^{-1} DM, in comparison to the respective nitrogen level without sulphur. Considering individual harvests, the highest increases in NEL were found in harvests 1 and 2, where increases up to 0.38 MJ kg^{-1} DM were found on Moosburg site.

Table 2. DM yield and feed quality parameters as influenced by sulphur and nitrogen application (data from 2016).

Site	N level	S level	DM yield t ha^{-1}	XP crude protein g kg^{-1} DM	XZ sugar g kg^{-1} DM	Fructan g kg^{-1} DM	NDF g kg^{-1} DM	NEL MJ kg^{-1} DM
Rockstedt	100% N	-S	15.40	160.3	66.5	29.8	577.6	6.13
	100% N	+S	15.85	155.9	80.1	38.5	568.6	6.15
	120% N	-S	15.43	145.3	87.1	45.5	571.1	6.15
	120% N	+S	16.78	174.0	80.1	34.8	563.6	6.22
	P-value (nitrogen)		0.31	0.92	0.48	0.43	0.43	0.34
	P-value (sulphur)		0.04	0.41	0.95	0.91	0.18	0.34
Kleve	100% N	-S	13.45	146.2	111.8	52.9	523.5	6.54
	100% N	+S	13.42	145.3	118.0	57.2	513.9	6.60
	120% N	-S	13.98	164.1	92.8	29.8	537.4	6.48
	120% N	+S	14.20	160.5	104.2	38.5	524.8	6.59
	P-value (nitrogen)		0.01	0.01	0.13	0.17	0.26	0.63
	P-value (sulphur)		0.75	0.87	0.53	0.48	0.34	0.11
Moosburg	100% N	-S	18.11	124.7	113.1	43.1	529.5	6.17
	100% N	+S	18.34	121.5	134.4	54.7	492.9	6.44
	120% N	-S	19.60	123.0	119.7	42.8	512.4	6.28
	120% N	+S	19.41	135.2	130.7	51.1	482.5	6.57
	P-value (nitrogen)		0.02	0.44	0.91	0.81	0.62	0.61
	P-value (sulphur)		0.98	0.58	0.05	0.03	0.08	0.08

Conclusion

Sulphur mineralisation from soil is not sufficient to supply intensively managed grassland adequately. This applies especially to sandy soils, where sulphate-S is easily leached, but also to other soils. An increase in DM yield and feed quality by additional sulphur application was found on various sites and soil types. The consistently lower NDF content and higher sugar content contribute to an increase in energy content and a better feed value of the grass which confirms pot studies results.

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Contrasting diets and milk composition on Galician dairy farms

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Abstract

Galicia (NW Spain), with an annual production of 2.7 M tonnes of dairy milk output, represents about 40% of total Spanish production. Lactating dairy cows feeding systems range from pasture grazing in smaller farms to all-silage based diets offered to confined animals in larger farms. The objective of this work is to describe the predominant dairy systems in terms of the diet composition offered, their nutritive value, milk yield and composition. A sample of 37 representative dairy farms were visited five times between October 2013 and September 2014, the diet offered to lactating cows was recorded and samples of feed ingredients and bulk tank milks were taken. Following a cluster analysis on diet composition, four typical diets were identified based on the predominant forage in the ration (FG: fresh grass, GS: grass silage, GS-MS: grass and maize silage and MS: maize silage). The milk solids (fat + protein) yield per cow and the concentrate use increased from 1.8 kg d^{-1} and 196 g kg^{-1} in FG to 2.4 kg d^{-1} and 284 g kg^{-1} in MS. Milk composition was affected by diet consumed, with lower fat but higher protein content in the maize-based silage systems.

Keywords: dairy cow, grazing, maize silage, grass silage, milk composition

Introduction

Galicia (humid-temperate NW Spain) is one of the European specialised dairy regions, with an annual production of 2.7 M tonnes of dairy milk output, representing about 40% of total Spanish output. It is within the 10 NUTS-2 regions with the highest level of dairy cow milk production in the EU (Eurostat, 2016). Much of Galician dairy farms have evolved in the last 30 years towards an intensification of forage production based on maize silage and concentrates with confined animals, whilst others maintain the traditional grazing system of grass in spring and autumn, coupled with the use of grass silage during summer droughts and winter. A number of intermediate feeding management systems can be found which combine the use of fresh and conserved forages with a varying degree of intensification and concentrate use. The objective of this work, based in a sample of 37 dairy farms, is to describe the predominant dairy systems in this area in terms of: a) composition of the predominant diets, b) nutritive value of the forage ingredients, c) cows productivity and chemical composition of milk.

Materials and methods

Thirty-seven representative farms were selected from a sample of 316 Galician dairy farms, which were interviewed to obtain information on their productive structure. Five visits took place on each farm between October 2013 and September 2014 where the diet offered to the lactating cows was recorded and samples of feed ingredients and bulk tank milk were taken for analysis. Diet composition was expressed in terms of the dry matter (DM) percentage of each ingredient (pasture, grass silage, maize silage, dry forage and concentrate) in the ration′s total DM. In grazing farms, the pasture intake was estimated using the equation DMI = 0.372 × MP4F + 12, adapted from NRC (2001), where DMI is DM intake (kg cow^{-1}) and MP4F is 4% fat corrected milk production (kg cow^{-1}). Pasture intake was calculated as the difference between DMI and intake DM of ingredients offered in the barn. Feed samples were analysed by NIRS (chemical composition, digestibility and pH) and milk samples were subjected to routine FTMIR analysis (chemical composition) in the official professional laboratory of milk analysis (Laboratorio Interprofesional Galego de Análise do Leite, LIGAL).

Data from a total of 178 valid observations were analysed using SAS package (SAS Institute, 2009), being grouped into clusters based on the composition of the ingredients, followed by an ANOVA analysis on diet, animal and milk parameters where the cluster was the classification variable (fixed factor).

Results and discussion

Average herd size was 38.1 (± 18.9) dairy cows, with 94.8% of cows Holstein. Out of the 37 farms, seven of them usually grazed grass swards with dairy cows throughout the year, with the remainder of farms using a feeding system based on grass and maize silages, in different proportions, with confined animals. Average values of main feed characteristics in terms of DM, chemical composition, digestibility and calculated net energy of lactation are shown in Table 1. The slightly low crude protein value in fresh grass and grass silage can be related to a moderate use of nitrogen fertiliser and a low clover presence in swards and/or to the maturity stage of the grass silage harvested.

Cluster analysis identified four typical diets (FG: fresh grass, GS: grass silage, GS-MS: grass and maize silages, MS: maize silage) based on the proportion of the predominant forage in the total DM (Table 2). Concentrate share in the total DM significantly increased from 228 g kg^{-1} for FG to 384 g kg^{-1} for MS, showing a gradient of intensification in diets with higher maize silage proportion. This trend was also indicated by the higher milk output (4% fat corrected, FCM) and milk solids (fat + protein) yield which increased linearly from 24.9 and 1.80 kg d^{-1} for FG to 27.9 and 2.02 kg d^{-1}, 30.1 and 2.19 kg d^{-1} and 32.8 and 2.39 kg d^{-1} for GS, GS-MS and MS, respectively. In parallel, estimated average feed efficiency, expressed as kg FCM produced per kg DM intake, increased from 1.17 to 1.25, 1.30 and 1.36 kg FCM kg^{-1} DMI in FG, GS, GS-GM and MS diets, respectively. Comparing the values of feed efficiency indicated by Erdman (2011) from US Holstein herds in mid lactation, corresponding GS and MS values can be regarded as similar (when corrected for the different milk fat content) whilst GS and FG values are clearly lower, indicating that there is more room for management improvements in those situations.

Fat, protein and lactose concentrations in milk samples, although significantly affected by diet, had a relatively narrow range (in g kg^{-1} milk) of 37.0 to 39.1 for milk fat, 32.0 to 32.8 for milk protein and 46.8 to 47.4 for milk lactose. The lowest value for fat corresponded to the MS diet whilst MS and GS-MS diets showed the highest values for milk protein and lactose. The annual average values (in g kg^{-1} milk) for the tank milk samples analysed in the LIGAL from more of 8,000 Galician dairy farms (37.3 for fat, 32.1 for protein and 47.2 g kg^{-1} for lactose) are, as expected, within the range of the observed values for the different diets.

Table 1. Dry matter content (g kg^{-1}), chemical composition (g kg^{-1} DM), organic digestibility (g kg^{-1}) and net energy of lactation (Mcal kg^{-1} DM) of diet's ingredients.[1]

	N	DM	OM	CP	ADF	NDF	CF	ST	OMD	NEL	pH
Fresh grass	18	189	889	150	296	490	-	-	692	1.55	-
Grass silage	194	371	917	114	362	563	-	-	631	1.33	4.6
Maize silage	153	324	964	70	252	468	-	289	699	1.58	3.8
Hay	50	866	940	64	416	707	322	-	540	1.10	-
Concentrate	142	865	944	199	80	-	59	333	897	1.99	-

[1] n: number of observations; DM: dry matter; OM: organic matter; CP: crude protein; ADF: acid detergent fiber; NDF: neutral detergent fiber; CF: crude fiber; ST: starch; OMD: OM digestibility; NEL: net energy of lactation.

Table 2. Herd size, estimated DM intake, feed efficiency, diet composition, milk yield, milk solids yield, milk composition and concentrate use by type of diet fed to the lactating cows.[1]

	FG	GS	GS-MS	MS	*P*
n	33	85	40	20	
Herd size (dairy cows)	32.9^{b}	34.1^{b}	35.4^{b}	53.0^{a}	***
DMI (kg cow^{-1})	21.2^{d}	22.4^{c}	23.2^{b}	24.2^{a}	***
Feed efficiency (kg milk kg^{-1} DMI)	1.17^{d}	1.25^{c}	1.30^{b}	1.36^{a}	***
Diet composition (g kg^{-1} DM)					
Fresh grass	482^{a}	86^{b}	5^{c}	0^{c}	***
Grass silage	137^{c}	401^{a}	285^{b}	63^{d}	***
Maize silage	88^{c}	86^{c}	318^{b}	478^{a}	***
Dry forages	66^{a}	77^{a}	24^{b}	75^{a}	***
Concentrates	228^{b}	350^{a}	369^{a}	384^{a}	***
Milk yield (kg cow^{-1} d^{-1})					
Milk (fat corrected)[†]	24.9^{d}	27.9^{c}	30.1^{b}	32.8^{a}	***
Milk Solids (Fat+Protein)	1.80^{d}	2.02^{c}	2.19^{b}	2.39^{a}	***
Milk composition (g kg^{-1} milk)					
Fat	38.8^{ab}	37.7^{bc}	39.1^{a}	37.0^{b}	**
Protein	32.3^{ab}	32.0^{b}	32.8^{a}	32.7^{a}	*
Lactose	46.8^{b}	47.1^{ab}	47.4^{a}	47.3^{a}	*
Concentrate use					
kg cow^{-1} d^{-1}	4.9^{c}	7.9^{b}	8.5^{ab}	9.3^{a}	***
g kg^{-1} milk	196.0^{b}	283.3^{a}	285.7^{a}	284.0^{a}	***

[1] FG: Fresh grass; GS: Grass silage; GS-MS: Grass and maize silage; MS: Maize silage; n: number of observations; DMI: Dry matter intake; [†] Milk corrected at 4.0% fat; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$

Conclusion

Four typical diets were found in Galician farms based on predominant forage levels offered to dairy cows. Silage diets, compared to fresh grass, corresponded with a more intensive system, with higher milk and milk solids yield but higher use of concentrate per cow, showing a gradient of intensification related to the importance of maize silage in the diet.

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Perennial ryegrass with/without clover on two farms in Flanders: Part I – crop yield and botanical composition

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Abstract

Nitrogen (N) fertilisation on grassland under cutting conditions in Flanders (Belgium) is currently restricted to 300 kg ha^{-1} N available from organic and chemical fertilisers. Combining perennial ryegrass (*Lolium perenne*, Lp) with red (*Trifolium pratense,* Tp) and white clover (*Trifolium repens,* Tr) is a possible alternative to achieve high crop yields and quality, at lower N fertilisation levels. On a farm in Moortsele and in Nieuwenhove with sandy loam soils, a paddock (> 0.75ha) was divided and one half was sown with a mono culture Lp and the other half with a Lp/Tp+Tr mixture. N fertilisation was in accordance with fertiliser recommendations i.e. Lp: 285 kg $N_{available}$ ha^{-1}year^{-1} and Lp/Tp+Tr: 180 kg $N_{available}$ ha^{-1}year^{-1}. Dry matter crop yields under cutting management (four - six cuts per year) were measured over four years. Grass clover swards resulted in an additional dry matter yield of +2 t ha^{-1}year^{-1} and +0.5 t ha^{-1} year^{-1} in Moortsele and Nieuwenhove, respectively while 86 kg N ha^{-1}year^{-1} and 81 kg N ha^{-1}year^{-1} of chemical N fertiliser was saved in Moortsele and Nieuwenhove, respectively during the same period.

Keywords: *Lolium perenne*, *Trifolium pratense*, *Trifolium repens*, nitrogen fertilisation, DM yield

Introduction

Nitrogen fertilisation on grassland under cutting conditions is restricted to 300 kg $N_{available}$ ha^{-1} in Flanders (Belgium) in accordance with the EU Nitrate Directive. High land prices are influencing dairy farmers to maximise yields and forage quality per area. The question being posed is can red and white clover in the sward improve the yield and quality of the forage in combination with the lower application rates of nitrogen fertilizers? Scientists are convinced of the potential of grass/clover in an intensive management system (De Vliegher *et al.*, 2015, Van Eekeren *et al.*, 2015) but many farmers in Flanders fear a decline in dry matter yields and quality when less N fertilisation on a grass/clover sward is used. This study was established on two farms to measure and demonstrate to farmers the potential of a grass/clover sward in terms of DM yield, quality and N fertiliser saving under intensive, real farm management conditions, i.e. where slurry is applied several times a year, the forage is pre-wilted during 1-2 days before harvesting with commonly-used farm machinery. This paper summarises the dry matter yield results with the red and white clover content in the sward during the years 2014-2017.

Materials and methods

The experiment was carried out as a strip design with three repetitions on a farm in Moortsele (loc. A) and Nieuwenhove (loc. B), both on sandy loam soil. Half of a paddock (> 0.75 ha) was sown with a Lp mixture of cv. Meloni and cv. Magistral (40 kg ha^{-1}) and the other half with the same Lp mixture + Tp cv. Merian and Tr cv. Merwi (30+7+3 kg ha^{-1}) in September 2013. The fertilisation level with Lp was 110, 80, 60 and 50 kg $N_{available}$.ha^{-1} in harvest 1, 2, 3 and 4 respectively, and Lp/Tp+Tr was 90 and 60 kg N ha^{-1} in harvest 1 and 2. Under farming conditions, the schedule for the N fertilisation depended on timing and quantity of cattle slurry applied, as well as soil and weather conditions. This resulted in an N fertilisation surplus on Lp/Tr+Tp. The N content of the slurry was measured and the nitrogen from slurry is available for the vegetation. It was spread over 4 successive cuts as follows: 36, 12, 6 and 6% of N_{total} (Rombouts *et al.*, 2014). Cattle slurry was applied and mineral nitrogen totaled 285 kg $N_{available}$ ha^{-1} year^{-1} for the Lp and 180 kg $N_{available}$ ha^{-1} year^{-1} for the Lp/Tp+Tr. The potassium fertilisation was

300 kg K_2O $ha^{-1}year^{-1}$ from slurry and KCl combined. For both Lp and Lp+Tp+Tr, a strip of 1.45 × 8 m was harvested in each block for every cut during the four years, just before the entire paddock was harvested. At each cut, dry matter (DM) yield was measured and a grab subsample from each strip was separated into the Lp, Tp, Tr and unsown species, dried and the percentage of each species was calculated on dry matter base. Samples were dried at 70 °C for 48 hours for dry matter content and NIRS analysis to determine chemical composition and digestibility (this edition of Grassland Science in Europe 2018). For each location, DM yield per harvest year and total DM yield for the period 2014 - 2017 was analysed with analysis of variance (Statistica 12.0 package) for the effect of forage type.

Results and discussion

In both locations the DM yield in the period 2014 - 2017 was significantly higher ($P < 0.01$) on grass clover in comparison with grass: +2.4 t ha^{-1} $year^{-1}$ in location A and + 0.5 t ha^{-1} $year^{-1}$ in location B (Table 1). Less nitrogen per ha was applied on grass/clover in this period: a decrease of 103 kg $N_{available}$ and 108 kg $N_{available}$ ha^{-1} in location A and location B, respectively. Less slurry was applied on Lp/Tp+Tr but financial savings were observed with less mineral fertiliser use i.e. 344 kg and 324 kg N in location A and location B, respectively over the entire four year period (86 kg N $ha^{-1}year^{-1}$ and 81 kg N $ha^{-1}year^{-1}$). Maximum savings of mineral N can be achieved on grass/clover when slurry is applied in spring and before the second cut because the N fertilisation on grass/clover is focused on these cuts. This was not always possible; in some years slurry could not be applied in spring because the (young) sward had not enough carrying capacity for the slurry tank or the grass/clover sward had an excessive grass cover to use a meadow injector/line spreading boom. In this situation more mineral N was applied for harvest 1 and 2. The mineral N use in location B in 2017 was high (160 kg N ha^{-1}) compared to the previous years because 40 kg $N_{mineral}$ ha^{-1} was applied in the third cut despite a good clover content in the sward at that time. Total annual input of chemical N fertiliser varied significantly on grass/clover but the important savings of more than 324-344 kg $N_{chemical\ fertiliser}$ ha^{-1} in a 4-year period on grass/clover compared to grass. As the clover content was in the range of 25-48% of the annual DM yield in 2014, 2015 and 2017 in both locations (Table1), N fertilisation could even be further reduced. The clover content and the

Table 1. DM yield, clover content of the sward and N fertilisation on grass (Lp) and grass/clover (Lp+Tp+Tr).

Year	Number of cuts	N-fertilisation slurry $N_{available/ha}$		Mineral N-fertilisation $N_{available/ha}$		DM Yield			Clover in sward
		Lp	*Lp+Tp+Tr*	*Lp*	*Lp+Tp+Tr*	*Lp (a)*	*Lp+Tp+Tr (b)*		*Tp+Tr*
						$t.ha^{-1}$	$t.ha^{-1}$	b/a	% in DM
Location A: Moortsele									
2014	6	215	130	81	68	16.5	18.3	111%	35+9
2015	6	99	117	203	41	12.0	15.5**	129%	36+6
2016	5	72	72	175	68	14.0	15.0	107%	6+19
2017	5	128	128	190	128	11.5	14.8*	129%	10+38
Average		129	112	162	76	13.5	15.9**	118%	23+17(1)
St. Dev.		54	23	48	32	2.0	1.4		
Location B: Nieuwenhove									
2014	5	157	50	137	90	17.7	19.4*	110%	27+3
2015	4	77	97	197	88	12.4	13.8*	111%	24+5
2016	4	98	99	149	41	16.1	15.3	95%	12+2
2017	5	80	58	220	160	16.5	16.3	99%	20+5
Average		103	76	176	95	15.7	16.2**	103%	21+4(1)
St. Dev.		37	26	39	49	2.3	2.4		

(1): weighed average; *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$

soil and weather conditions determine the quantity of N fixation and the effect on DM yield and grass quality. The clover proportion in the sward decreased significantly in the third year but increased again in the fourth year due to a very dry period in June - July. Over the years, the clover content was higher in location A in comparison with location B (40 vs 25%) due to white clover (17 vs 4%) while red clover content was almost the same (23 vs 22%). A difference in the persistency of red or white clover in the sward during the four year period was also observed. In location A, a decline in red clover and an increase in white clover content took place in the sward over the years (Table 1). This confirms the difference in persistency between the red and white clover varieties used in this experiment (Pannecoucque *et al.*, 2017). In Location B, red clover content was lower in the first two years but persisted well while white clover content was low from the very beginning and did not improve as expected.

Conclusion

Grass/clover (180 kg $N_{available}$ ha^{-1} $year^{-1}$) was compared with grass (285 kg $N_{available}$ ha^{-1} $year^{-1}$) in a cutting system under intensive, farming conditions during four years in two locations in Flanders. The DM yield, 2.4 t DM ha^{-1}·$year^{-1}$ in location A and 0.5 t DM ha^{-1}·$year^{-1}$ in location B was significantly higher ($P < 0.01$) in grass clover swards. Less mineral fertiliser was applied: 86 kg N $ha^{-1}year^{-1}$ in location A and 81 kg N $ha^{-1}year^{-1}$ in location B. Despite high N fertilisation, the clover content over the years remained reasonable in both locations but was higher in location A due to better white clover development.

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Perennial ryegrass with/without clover on two farms in Flanders: Part II – nutritive value of fresh material and silage

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Abstract

Combining *Lolium perenne* (Lp) grass with *Trifolium pratense* (Tp) and *Trifolium repens* (Tr) is an alternative to achieve high crop DM yields and quality at lower N fertilisation levels. At two locations, an individual paddock was sown with Lp with and without Tp+Tr, managed under cutting and fertilised with 285 kg N ha^{-1} $year^{-1}$ and 180 kg N ha^{-1} $year^{-1}$ respectively. Forage samples were taken when the swards were cut and 1-2 days later when the forage was transported to the silo. DM (g kg DM) content, crude protein (CP), true protein digested in the small intestine (DVE), rumen degraded protein balance (OEB) and fodder unit milk (VEM) were determined in the samples. Lp+Tp+Tr with a high proportion of red and white clover had a tendency to be lower in DM, higher in CP and OEB, but had the same values for DVE and VEM in comparison with Lp, at the time of cutting and as prewilted silage.

Keywords: perennial ryegrass, clover, nutritive value, fresh matter, silage

Introduction

Scientists are convinced of the potential of grass/clover in an intensive management system but many farmers in Flanders are fearful that dry matter yields and quality will decline when less N fertilisation on a grass/clover sward is applied. This experiment took place on two farms, to measure and to demonstrate to farmers the potential of a grass/clover sward in terms of DM yield, quality and N fertiliser saving under intensive, real farm management conditions where slurry is applied several times a year. This paper summarises the nutritive value of the fresh forage and the silage in 2014-2016.

Materials and methods

The experiment was carried out in paddocks on a farm in Moortsele (loc. A) and Nieuwenhove (loc. B), both on sandy loam soils. Half of a paddock (> 0.75 ha) was sown with Lp and the other half with Lp+Tp+Tr in 2013 and managed in a four - six cutting regime in 2014 - 2017. The experiment was carried out as a strip design with three repetitions. Seeding density, composition of the seed mixture, N fertilisation regime, DM yield and the botanical composition in this experiment is described (De Vliegher *et al*., 2018, this edition). Lp and Lp+Tp+Tr was sampled in each block at cutting. At each cut, fresh forage yield was measured in three strips in 2014 - 2017. After two days of wilting Bokashi containers (15l), used for air free storage of organic material were filled with prewilted Lp(/Tp+Tr) from each block. A limited number of late harvests were not sampled for silage. After a fermentation period of 12 weeks in these containers, silage was sampled. Fresh forage (at the time of cutting) and silage samples were dried at 70 °C for 48 hours for DM content and analysed with NIRS to determine chemical composition and cellulose organic matter digestibility (De Boever *et al*., 1988). These parameters were used to predict the net energy for lactation (VEM) according to Van Es (1977) and the DVE and OEB according to Tamminga *et al.* (1994) for fresh forage and silage using developed regression equations (De Boever, 2017). For both locations, data for DM, CP, VEM, DVE and OEB, the effect of forage were analysed per cut in the period 2014 - 2016 by ANOVA with main factors block, year and treatment using Statistics 12.0 package.

Results and discussion

The Tp+Tr content in the sward was high in 2014 and 2015: ≥35 ± 9% in loc. A and ≥ 24 ± 5% in loc. B (De Vliegher *et al.*, 2018). The DM, CP, energy and protein values of Lp(/Tp+Tr) at the time of cutting are given in Table 1. Lp+Tp+Tr had a significantly lower DM content in every cut in location A and in the last three cuts of location B. In the first two cuts differences were small but in the fourth and later cuts, the differences were at least 4%. This is related to the clover content and the leafiness of red clover at the time of harvest.

The CP content in Lp+Tp+Tr was higher in each cut although not always significant and the differences were large in the cuts four to six taken at the end of August until the end of October. This resulted in a similar evolution of the OEB and small differences in DVE between Lp and Lp+Tp+Tr. The VEM content of Lp and Lp+Tp+Tr of the fresh forage was similar. The DM and CP content and the nutritive values of Lp(/Tp+Tr) silage from location A are given in Table 2. The results of location B are not presented but show the same tendencies. A high yield and high clover content in the sward in combination with

Table 1. Dry matter (DM) and crude protein (CP) content and nutritive values of Lp(/Tp+Tr) fresh forage.

Cut no.		DM content g kg^{-1} fresh matter	CP content g kg^{-1} DM	VEM[1] g kg^{-1} DM	DVE[2] g kg^{-1} DM	OEB[3] g kg^{-1} DM
Location A: Moortsele (2014-2016)						
1	Lp[4]	206	152	997	91	0
	Lp+Tp+Tr	186*	178*	995	93	21*
2	Lp	167	157	916	76	14
	Lp+Tp+Tr	146*	166	927	81	19
3	Lp	210	117	977	81	-26
	Lp+Tp+Tr	184*	160*	956*	85	10*
4	Lp	239	143	883	68	8
	Lp+Tp+Tr	193*	197*	873	68	55*
5	Lp	236	150	859	65	15
	Lp+Tp+Tr	148*	236*	907*	77*	85*
6	Lp	185	159	878	73	18
	Lp+Tp+Tr	145*	242*	897	82*	89*
Location B: Nieuwenhove (2014-2016)						
1	Lp	205	128	989	86	-20
	Lp+Tp+Tr	191	140	993	90	-12
2	Lp	187	124	859	61	-6
	Lp+Tp+Tr	179	137	855	63	5
3	Lp	207	133	893	70	-3
	Lp+Tp+Tr	187*	142	877	67	6
4	Lp	240	138	813	56	8
	Lp+Tp+Tr	181*	186*	835	62*	49*
5	Lp	161	132	867	67	-3
	Lp+Tp+Tr	123*	199*	866	71	56*

[1] Fodder unit milk.
[2] True protein digested in the small intestine.
[3] Rumen degraded protein balance.
[4] Lp: *Lolium perenne*; Tp: *Trifolium pratense*; Tr: *Trifolium repens*.
* indicate per cut, the parameter where Lp+Tp+Tr is significantly different ($P < 0.05$) from Lp.

Table 2. Dry matter (DM) and crude protein (CP) content and nutritive values of Lp(/Tp+Tr) silage in location A.

Cut no.		DM content g kg^{-1} Fresh matter	CP content g kg^{-1} DM	VEM[1] g kg^{-1} DM	DVE[2] g kg^{-1} DM	OEB[2] g kg^{-1} DM
Location A: Moortsele (2014-2016)						
1	Lp	388	179	974	78	38
	Lp+Tp+Tr	371	200*	968	80	55*
2	Lp	319	177	903	70	39
	Lp+Tp+Tr	294*	183	880*	67*	46
3	Lp	354	146	927	67	11
	Lp+Tp+Tr	313*	187*	880*	67	48*
4	Lp	331	157	867	61	24
	Lp+Tp+Tr	259*	194*	827*	59	57*
5	Lp	477	174	874	65	35
	Lp+Tp+Tr	307*	238*	893	75*	92*

[1] Fodder unit milk.

[2] True protein digested in the small intestine.

[3] Rumen degraded protein balance.

[4] Lp: *Lolium perenne*; Tp: *Trifolium pratense*; Tr: *Trifolium repens.*

* indicate per cut, the parameter where Lp+Tp+Tr is significantly different ($P < 0.05$) from Lp.

a short wilting period resulted in a low DM content of the grass/clover silages, which was significantly lower than in grass silage except in the first cut. The CP and the OEB content of the Lp+Tp+Tr silage was almost always significantly higher compared with Lp silage and the differences increased further in the growing season.

Differences in DVE between Lp+Tp+Tr and Lp silage were small and mostly not significant. The VEM content of Lp+Tp+Tr silage was significantly lower in cuts 2, 3 and 4, similar in cut1 but higher in cut 5.

Conclusion

In this experiment, in two farm locations under cutting and real farm conditions, Lp+Tp+Tr swards with a high proportion of red and white clover generally had a significantly lower DM content, significantly more CP and OEB and similar content of DVE and VEM in comparison with Lp as fresh forage and as prewilted silage.

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Peas as a cover crop for clover and lucerne installation in Flanders

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Abstract

In Merelbeke (Flanders), red clover (*Trifolium repens*) and lucerne (*Medicago sativa*) were sown in a pure stand and in combination with white clover (*Trifolium pratense*) and perennial ryegrass (*Lolium perenne*) in two, two-year field trials (A: 2015-2016 and B: 2016-2017). All these treatments were sown in spring with and without peas (*Pisum sativum*). Over the year, the average dry matter (DMY) production of the legume/grass mixtures with peas as a cover crop was significantly higher (+18%) in comparison with the same mixtures without peas in both experiments in the installation year. A significant difference in crude protein yield (CP) of + 7% was noted between treatments with and without peas in experiment A and + 14% in experiment B. Due to the difference in N fixation capacity of the legumes and the low N fertilisation of perennial ryegrass monoculture, the additional CP production by adding peas as cover crop is quite different between pure legumes (0.03 - 0.16 Mg CP ha^{-1}), legume/perennial ryegrass mixtures (0.07 - 0.26 Mg CP ha^{-1}) and pure perennial ryegrass (0.68 - 0.66 Mg CP ha^{-1}). In both experiments no effect of the cover crop was observed in the second year.

Keywords: peas, cover crop, forage legumes, dry matter, protein yield

Introduction

The installation of grass or forage legumes as lucerne and clover is more difficult when sown in spring in comparison with sowing in August; this can affect the yield at least in the first growing season. Peas sown in spring as a cover crop for new grass clover is quite common in organic farming in Belgium and the Netherlands. Peas are harvested at early ripening as pre-wilted silage. Pea as cover crop in grass/legume forage crops is only meaningful when the dry matter yield (DMY) and crude protein (CP) production of the forage crops remain high after pea harvest -both in the year of sowing and the following years. In this paper the results of dry matter and protein yield of the sowing year and the effect of the cover crop on the forage crops are discussed.

Materials and methods

Two experiments (A and B) with seven mixtures of grass, clover and lucerne were carried out in Merelbeke (region of Flanders, northern Belgium). Experiment A and B were carried out on the same field (sandy loam; pH_{KCl}= 6.0; C% = 1.4%) had exactly the same experimental setup and were sown in April 2015 and April 2016, respectively. Both were followed up in the year of sowing (three cuts) and the year after (five cuts). The preliminary results of experiment A were published in De Vliegher *et al.* (2017). Seven mixtures were sown with and without peas in April 2015 (A) and April 2016 (B): (1) LU (lucerne 25 kg ha^{-1}), (2) LU+WCL (lucerne 25 kg ha^{-1} + white clover 3 kg ha^{-1}), (3) RCL (red clover 15 kg ha^{-1}), (4) RCL+WCL (red clover 12 kg ha^{-1} + white clover 3 kg ha^{-1}), (5) LU+PR (lucerne 12.5 kg ha^{-1} + perennial ryegrass 20 kg ha^{-1}), (6) RCL+WCL+PR (red clover 8 kg ha^{-1} + white clover 3 kg ha^{-1} + perennial ryegrass 20 kg ha^{-1}) and (7) PR (perennial ryegrass 35 kg ha^{-1}). The lucerne seeds were inoculated with *Rhizobium meliloti*. Peas (220 kg ha^{-1}) were sown 4 cm deep and the forages 1cm deep. No herbicides were used. The fertilisation was the same for the plots with and without peas. K fertilisation was 80 kg K_2O ha^{-1} and 240 kg K_2O ha^{-1} in the sowing year and the second year, respectively. The N fertilisation of perennial ryegrass (7) was 80 kg N ha^{-1} in the sowing year and 300 kg N ha^{-1} in the second year. The grass/legume mixtures (5 and 6) received only 120 kg N ha^{-1} in the second year. The pure legumes (1, 2, 3, 4) received no N fertiliser. The trial design was a split plot design with mixtures in the subplots and three replicates. The Fisher test was used for multiple comparisons. Field plots of 6 × 1.5 m were harvested with a Haldrup forage harvester at a cutting height of 5 cm. Dry matter yields (DMY) of each replicate were calculated after drying the subsample in a forced-draft oven at 80 °C for 24 hours. These samples were analysed by NIRS to determine crude protein content and other nutritional parameters. To determine the botanical composition, a grab subsample per plot was separated into the individual sown species.

Results and discussion

In the sowing year, the average Dry Matter Yield (DMY) of the first cut and the total DMY was significantly increased in both experiments by the presence of peas as cover crop (Table 1). About 91 and 88% of the DMY of the first cut were peas in experiment A and B, respectively. The cover crop increased the total DMY over all mixtures and both experiments on average with 18%. The positive effect was, however, also significantly influenced by the type of mixture. The biggest advantages were measured on PR for both experiments (A: +52% and B: +45%) and on RCL+WCL+PR for experiment B (+47%). The advantages on the pure stands of the legumes were smaller in both experiments. This can be explained by the N fixation capacity of clover and Lucerne and the low N fertilisation of the pure stand of perennial ryegrass. The perennial ryegrass was fertilised according to the maximum legally allowed N-fertilisation level in Flanders, which is about 100 kg N ha^{-1} below the level of maximum crop yield. There is no explanation for the large positive effect of the cover crop on RCL+WCL+PR in experiment B, where practically no perennial ryegrass was observed in the botanical composition. The lower DMY of LU in experiment B can be explained by the poor installation in the very wet conditions during spring 2016 and June 2016 (200 to 250% of normal rainfall). There was a significant interaction between the total DMY of the mixtures and the experiment. This was expected, as the sowing years (A: 2015 and B: 2016) were very different and had an important effect on the installation of the mixtures. The effect of peas as a cover crop on the weed suppression could not be evaluated here because the number of weeds was very low. In the other cuts no peas and no unsown species were detected. There was no significant effect of peas as cover crop on the DMY of mixtures in the second year in both experiments.

In both experiments, the cover crop increased the CP yield in the sowing year (A: + 7% and B: + 14%) (Table 2), although this was only significant in experiment A. Considering three groups of mixtures (legumes, legumes/grass and grass), the increase in the total CP yield by adding peas as a cover crop is the

Table 1. Dry matter yield (Mg ha^{-1}) of the first cut and the total dry matter yield (3 cuts) in the sowing years of the mixtures with or without peas as a cover crop for both experiments.

	Dry matter yield Cut 1				Total dry matter yield			
	Experiment A (2015)		Experiment B (2016)		Experiment A (2015)		Experiment B (2016)	
Peas	No	Yes	No	Yes	No	Yes	No	Yes
Average DMY	3.62	7.39	3.91	6.18	9.88	11.65	9.47	11.19
	$P < 0.001$		$P < 0.001$		$P < 0.001$		$P < 0.05$	
1 LU	3.98^{a}	7.22^{b}	1.84^{d}	5.43^{d}	11.09^{a}	11.92^{ab}	7.32^{c}	9.20^{b}
2 LU + WCL	3.87^{a}	6.97^{c}	5.68^{a}	6.65^{ab}	9.48^{c}	11.52^{bc}	12.24^{a}	12.73^{a}
3 RCL	3.82^{a}	7.50^{ab}	5.89^{a}	6.46^{abc}	9.34^{c}	11.20^{c}	12.48^{a}	12.71^{a}
4 RCL + WCL	3.71^{a}	7.40^{ab}	3.48^{b}	5.87^{cd}	11.05^{a}	11.78^{ab}	8.28^{b}	10.16^{b}
5 LU + PR	3.78^{a}	7.70^{a}	5.88^{a}	6.91^{a}	10.09^{b}	11.71^{abc}	12.13^{a}	13.34^{a}
6 RCL + WCL+ PR	3.82^{a}	7.43^{ab}	2.18^{c}	6.01^{bcd}	10.73^{a}	12.20^{a}	6.91^{c}	10.15^{b}
7 PR	2.41^{b}	7.50^{ab}	2.44^{c}	5.94^{bcd}	7.35^{d}	11.18^{c}	6.93^{c}	10.07^{b}

Treatments with the same letter in a column are not significantly different ($P < 0.05$).

Table 2. Crude protein yield (Mg ha^{-1}) (three cuts) in the sowing years of the mixtures with or without peas as a cover crop for both experiments.[1]

	Experiment A (2015)		Experiment B (2016)	
Peas	No	Yes	No	Yes
Average total CP yield	1.80	1.93	1.75	2.00
	$P < 0.001$		NS	
1 LU	2.21^{a}	2.09^{a}	1.45^{c}	1.70^{cd}
2 LU + WCL	2.15^{a}	2.14^{a}	2.24^{a}	2.31^{a}
3 RCL	1.76^{c}	1.89^{bc}	2.34^{a}	2.37^{a}
4 RCL + WCL	1.77^{c}	1.88^{bc}	1.75^{b}	2.02^{b}
5 LU + PR	2.02^{b}	2.01^{ab}	2.33^{a}	2.39^{a}
6 RCL + WCL+ PR	1.74^{c}	1.88^{c}	1.25^{d}	1.70^{c}
7 PR	0.95^{d}	1.63^{d}	0.87^{e}	1.53^{d}
Legumes (1, 2, 3, 4)	1.97	2.00	1.94	2.10
Legumes/grass (5, 6)	1.88	1.95	1.79	2.05
Grass (7)	0.95	1.63	0.87	1.53

[1] Treatments with the same letter in a column are not significantly different ($P < 0.05$).

highest for grass in pure stand in both experiments. This can be explained by the N fixation capacity of the legumes and the low N fertilisation of the grass (see earlier). There were no significant effects of peas as cover crop on the total CP yield of the mixtures in the second year in both experiments (data not shown).

Conclusion

The total DMY was increased by 18% on average for both experiments in the sowing year across all mixtures due to addition of peas as a cover crop. The CP yield was increased by 7% in experiment A and 14% in experiment B. The effect of the cover crop was higher in perennial ryegrass than in the pure legumes and grass/legume mixtures, as a result of the N fixation by the legumes and a low N fertilisation for perennial ryegrass. The low yields for lucerne in experiment B illustrate the importance of the soil and weather conditions on the success of installation of legumes. There was no long-term effect of peas as a cover crop on the DMY and CP of the mixtures.

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Joint technical and economic assessment of feed autonomy in organic cattle farms

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Abstract

Increasing the level of feed autonomy (self-sufficiency) is usually considered as a prerequisite for conversion of cattle farms to organic farming. Technically it requires adjusting fodder production and feed purchases in terms of quantity and quality to the requirements of the herd. A joint technical and economic assessment of feed autonomy in organic cattle farms was conducted. Data were collected in 2014 and 2015 on 11 Belgian farms located in distinct agricultural regions and characterised by different proportions of grassland area. Dry matter yield and nutritional quality were determined at each harvest for each fodder crop, including permanent and temporary grasslands, immature cereal-legume crops and grain crops. Animal productions and economic data, including all cash inflows and outflows, were recorded. Economically efficient farms had high levels of feed autonomy, ranging from 89 to 100%. Three economically-efficient feeding strategies were identified for organic cattle production. Strategies differed from each other according to the proportion of grassland area, level of animal production and the achieved level of feed autonomy.

Keywords: grassland, dairy farm, beef farm, organic, feed autonomy, economic efficiency

Introduction

Increasing the level of feed autonomy (self-sufficiency) is usually considered as a prerequisite for conversion of cattle farms to organic farming. The EU policy imposes that animals raised in organic conditions have permanent access to pastures or rough fodder. High prices of organic feeds encourage farmers to limit feed purchases as much as possible. Increasing the level of feed autonomy is not easy to complete. It requires adjusting fodder production and feed purchases in terms of quantity and quality to the requirements of the herd which depend on the animal performances. The right adjustment is found when the difference between incomes and total feed costs is maximised. Options for fodder production are grazed pastures, temporary grasslands, immature cereal-legume crops, grain cereal crops and protein crops, each of them with a large diversity of options regarding the species composition. The choice of fodder crops is constrained by the agro-ecological conditions of the cultivation area.

To date, feed autonomy in Walloon cattle farms has been studied from technical or economic data independently (Bernes *et al.*, 2011; Lebacq *et al.*, 2014). In this paper, a joint technical and economic assessment of feed autonomy in organic cattle farms was conducted in order to identify efficient strategies for organic cattle production.

Materials and methods

Data were collected in 2014 and 2015 on 11 organic farms, six dairy and five beef farms. Farms were located in distinct agricultural regions in Wallonia (Belgium) and numbered by type of production, milk (M) or beef (B), and increasing percentage of permanent grassland area (PPG) in the total cultivated area (Table 1). Out of the beef farms, farms B2, B4 and B5 were sucklers only ('breeders'), while B1 and B3 were also fatteners ('breeders-fatteners').

Fodder production was characterised in terms of quantity and nutritional quality (Van Es, 1975; Tamminga *et al.*, 1994). Dry matter (DM) production from grazed pastures was estimated by analysing grazing calendars using the model developed by Delagarde *et al*. (2017). For dairy farms, milk production was recorded by the farmer and expressed per dairy cow. For beef farms, the annual liveweight production was calculated over the entire herd and expressed per suckler cow. This was achieved by taking into account livestock variations and by estimating the weight of each animal as a function of its age using a growth model parameterized on breed-respective data. All cash in- and outflows were recorded. For the sake of comparability, feed production costs were restricted to crop inputs and fodder storage costs.

Different indicators were computed to assess the farm performances. Those included the level of feed autonomy (FA) and the weighted average crude protein (CP) content of self-produced and purchased DM. The technical feed efficiency (TE) was computed as the ratio between total amount of produced milk or liveweight and total amount of consumed DM. The economic feed efficiency (EE) was computed as one minus the ratio between total feed cost (feed production costs and feed purchases) and gross product without subsidies. Finally, the cost price of consumed self-produced dry matter (CostP-self) and the cost price of the total consumed feeds (CostP-tot) were computed. Data were analysed using the R software.

Results and discussion

The PPG increased from 33 to 100% in dairy farms and from 62 to 86% in beef farms (Table 1). Dairy farms M5 and M6, located in Ardenne, had permanent grasslands only. Grain cereal crops were found in all farms with the exception of M5 and M6 and two beef farms, B2 and B5. Average dry matter yields, computed over grazed pastures and fodder and grain crops, were highest in farms located in the Loam region (M1 and B1) and lowest in farms located in Famenne (M3 and B2). In terms of animal productions, farms M1 and B1 were the most intensive ones, and, on the opposite, farms M2 and B2, B4, and B5, the least intensive ones.

FA ranged between 78 and 100%, with highest levels found in farms M1, M2, B1, B3 and B4 (≥ 98%) and lowest levels in farms M3 and B2, located in Famenne. The average CP content of self-produced feed increased from 11.5 to 17%. It was highest in M5 and M6, the two farms that included permanent grasslands only. The average CP content of purchased feeds was highest in farms M1 and B1, which were also characterised by the highest TE. Farms with high TE also had high EE but no relationship was observed between TE and EE.

A focus was put on farms with EE higher than 80% (thus farms M3 and B2 were discarded). Economically efficient farms had high FA, ranging from 89 to 100%. FA was lower in farms with only grasslands ($P < 0.001$). These farms were also characterised by lower CostP-self ($P < 0.05$). The relationship between CostP-tot and PPG was not significant, suggesting that low CostP-self were at least partly compensated by larger feed purchases.

Based on this survey we identified three economically-efficient feeding strategies for organic cattle production. Strategy 1 is characterised by a grass-based production with FA of 89-94%. It includes dairy farms with an intermediate milk production level and breeder beef farms (farms M5, M6 and B5). Strategy 2 is characterised by a multiple crops-based production with FA of 94-99%. It includes dairy farms with a high milk production level and breeder-fattener beef farms (farms M1, M4, B1 and B3). Strategy 3 is characterised by both grassland and crop productions, with FA close to 100%. It includes dairy farms with a relatively low milk production level and breeder beef farms (farms M2 and B4).

Table 1. Fodder productions, animal productions and technical and economic performance of 11 organic cattle farms in Belgium, over two years, 2014 and 2015.

	Milk farms[1]						Beef farms[1]				
	M1	M2	M3	M4	M5	M6	B1	B2	B3	B4	B5
Agricultural region	Loam region	Sandyloam region	Famenne	Ardenne	Ardenne	Ardenne	Loam region	Famenne	Ardenne	Ardenne	Condroz
Fodder production											
Permanent grasslands (%)	33	48	63	78	100	100	62	68	72	81	86
Temporary grasslands (%)	37	15	14	6	0	0	10	3	19	6	14
Immature cereal-legume crops(%)	0	9	9	0	0	0	18	29	0	0	0
Grain cereal crops(%)[2]	30	27	14	9	0	0	5	0	9	13	0
Protein crops(%)	0	0	0	7	0	0	5	0	0	0	0
Average dry matter yield (kg DM ha^{-1})	7,381	5,509	4,220	4,980	6,329	5,607	7,208	3,702	4,530	5,200	5,926
Animal productions											
Milk production (kg milk dairy cow^{-1} $year^{-1}$)	7,292	3,629	5,267	6,596	5,263	5,466	-	-	-	-	-
Beef production (kg liveweight suckler cow^{-1} $year^{-1}$)	-	-	-	-	-	-	618	239	332	227	227
Animal production sale price (€ kg milk or $liveweight^{-1}$)	0.45	0.36	0.56	0.43	0.49	0.48	3.33	1.38	1.71	1.69	1.91
Technical and economic performances											
Stocking rate (LU ha^{-1}) [3]	1.34	1.43	1.09	1.14	0.98	1.18	1.90	1.02	0.93	1.24	1.68
Level of feed autonomy (%)	99	100	78	94	93	89	98	85	98	99	94
Crude protein content of self-produced DM (%)	14.6	14.2	13.8	15.6	17.0	16.8	15.4	13.4	13.8	11.5	13.0
Crude protein content of purchased DM (%)	48.8	0	13.6	11.2	12.2	15.1	25.5	14.5	15.9	4.7	11.4
Feed technical efficiency (kg of milk or liveweight/100 kg of consumed DM)	73.5	64.3	64.9	85.4	67.3	70.6	8.4	6.0	5.6	4.7	3.9
Feed economic efficiency (%)	89.3	80.7	61.8	83.8	92.4	89.3	87.3	47.3	89.1	91.2	89.1
Cost price of self-produced feed (€ tDM^{-1})	27.0	36.6	69.2	21.7	8.0	17.0	17.2	26.4	9.1	4.4	13.0
Cost price of total consumed feed (€ tDM^{-1})	36.8	46.6	139.5	53.9	26.8	40.0	33.9	40.4	18.5	5.8	15.6

[1] Farms are numbered according to their % of permanent grasslands. Out of the beef farms, farms B2, B4 and B5 are sucklers only ('breeders'), while B1 and B3 are also fatteners ('breeders-fatteners'); [2] Grain cereal crops include both pure cereal crops and cereal-legume mixtures cultivated for grain.; [3] LU - livestock unit.

Conclusion

This study focused on the joint analysis of technical and economic data from organic dairy and beef farms. Based on 11 farms analysed over two years, it enabled three distinct economically-efficient feeding strategies to be identified for organic cattle production.

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Ecosystem services provided by hay meadows in Iberian mountain areas: evolution and perspectives

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Abstract

Hay meadows represents agro-ecosystems maintained by secular extensive management of rural communities throughout Europe. Their progressive disappearance (especially in mountain areas) represents a significant loss of biodiversity and ecosystem services. This study aimed at carrying out a general diagnosis of ecosystem services (ES) provided by hay meadows in the Iberian Peninsula, focusing on mountain areas located in the North of Spain and Portugal, most of which are currently protected areas or/and Natura 2000 sites. The conceptual framework developed in the Millenium Ecosystem Assessment has been applied to characterise and assess the most relevant ES, as well as to analyse their evolution and driving forces in the last decades, based on published data and expert opinion. As the area of hay meadows has been decreasing notably over the last 60 years in this area, a general loss in the supply of fundamental ES for the well-being of our society is taking place. The study also briefly discusses possible responses to tackle this decline.

Keywords: ecosystem services, mesophile hay meadows, mountains, South-West Europe

Introduction

Hay meadows are secular agro-ecosystems maintained by humans, indispensable for forage provision and European rural landscapes. Their traditional extensive management still survives in south west European (SW-EU) mountain areas, where grazing by livestock in autumn and spring is combined with mowing in summer (when livestock moves to rich grasslands in upper elevations). Hay meadows are decreasing notably in this area mainly due to their conversion into grasslands or their abandonment and later conversion to forest or scrubland. Analyses carried out in pilot mountain areas in the north west Iberian Peninsula show reductions of hay meadows surfaces about 68% (National Park of Picos de Europa) and 10% (Natural Parks of Alvão y Montesinho/Nogueira) between 1956 and 2017. Changes in area and distribution of these systems, which are expected to reduce the supply of certain strategic ES to society, however, have been only partially analysed. In this study we carried out a qualitative assessment of ES relevance provided by hay meadows in mountain areas in SW-EU and trends in their supply, as well as the driving forces causing such changes and future perspectives to guide possible responses and management measures for these areas.

Materials and methods

The study is focused on mesophile hay meadows at 700 - 1,300 metres in altitude, located in three pilot mountain zones included in protected areas and/or Natura 2000 sites: the National Park of *Picos de Europa* (Cantabrian mountains, NW Spain) and the Natural Parks of *Alvão* and *Montesinho/Nogueira* (N Portugal). Adopting the conceptual framework of the *Millenium Ecosystem Assessment* (MA, 2003), we analysed ES in these sites based on the assessment of their importance (ordinal scale classes 'Very high', 'High', 'Moderate' and 'Low') and trends ('Fast growth', 'Growth', 'Steady, mixed or non-defined trend', 'Decrease' and 'Fast decrease') over the last 60 years (1956 - 2017). Previous results from Spanish and Portuguese national assessments (EME, 2011; Aguiar *et al.*, 2009) were taken as starting points for the assessment which was completed with authors′ prior knowledge and information from phytosociological and socioeconomic sampling and evolutionary analyses in these areas (García Manteca *et al.*, 2017; Honrado *et al.*, 2017; Aguiar and Azevedo, 2011; Pires *et al.*, 1994) as well as expert opinion (three experts in Portugal, three experts in Spain). Direct and indirect drivers of changes in ES provision corresponding to categories set by the MA (2003) and EME (2011) conceptual frameworks and their importance and trends were assessed by using the aforementioned ordinal scales. Results were organised in ES/Importance and ES/Trend matrices from which final scores for each ES class were calculated.

Results and discussion

According to published information and the opinion of experts, mesophile hay meadows agro systems are essential in the provision of supporting ES (primary production, soil formation-retention-fertility, habitat), but these services are in a clear decreasing trend (very strong in the Spanish case study) due to a fast reduction of their area over the last 60 years. Forage production tends also to decrease, associated to higher grazing and changes in traditional fertilisation. The transformation of these open, permanent herbaceous systems interconnected in the landscape contributes to permanent loss of unique habitats in some of the species richest sites in Europe. Simultaneously, the reduction in area of meadows in Spanish mountains leads to a strong decrease in the supply of important regulating ES such as climate regulation (C sequestration and storage), hydrological regulation (flooding and drought control, runoff control, maintenance of soil moisture in steep slopes), water quality regulation (filtering and degradation of contaminants), and soil loss regulation (soil retention and control of landslides). In Portuguese mountains, the trend is less clear. In fact, due to the replacement of meadows by shrub communities and young forest stands, globally these northern mountain areas in Portugal show an increasing supply of these ES (Sil *et al.*, 2016). Other regulating ES such as risk control (forest fires) and pollination, of high importance and irreplaceable in these areas, tend to decrease in supply.

Hay meadows genetic resources are fundamental provisioning ES currently threatened by loss of agrobiodiversity. Traditional use of seeds has practically disappeared in favour of a growing use of commercial and non native varieties. Although populations of local autochthonous cattle and sheep breeds have suffered from a strong decrease, diversity of plant and animal species (e.g. insects) typical of hay meadows remain steady for the moment. Other threatened provisioning ES in hay meadows are animal products (meat, milk, cheese, honey), with very high economic importance for local economies and cultural value; nevertheless, their decline has been alleviated (particularly in *Picos de Europa*, Spain) by using geographical and traditional indications and economic support for the conservation of autochthonous breeds.

With the exception of traditional knowledge, the majority of cultural ES associated with mountain hay meadows has improved in the last 60 years, particularly scientific knowledge and educational values, aesthetics and inspiration, sense of identity and place and cultural heritage, as a result of an expanding urban society increasingly demanding culturally (tangible and intangible) and visually appealing environments where hay meadows are seen as identitary symbols of the rural landscape.

Land use change and over and under exploitation (mainly abandonment) have been identified as major direct drivers (pressures) of these changes, under the influence of indirect drivers such as socio-demographic changes (depopulation, aging), the Common Agricultural Policy (CAP), mechanisation, and urbanisation of rural communities. All drivers show a growing trend in the studied areas. Conservation of hay meadows is a way of assuring the supply of diverse and fundamental ES to the society. CAP and national Rural Development Programmes, risk prevention and climate change mitigation plans, environmental education and R&D&I programmes, are examples of policy and planning instruments that can contribute to the maintenance of these systems. Hay meadows are strategic in rural areas, in particular in mountain areas, where they provide safe and healthy food products, contribute to the reduction of fire hazard in the landscape, to the development of new products and the establishment of new industries, allowing the preservation and recovery of traditional knowledge. Raising the profitability of meadows through increasing support from existing policies (e.g. agri-environmental subsidies), and institutions (e.g. protected areas), better access to markets of bio-based agricultural products and the development of new ecosystem services´ payment schemes, is an essential step for their maintenance.

Conclusion

The identification and assessment of ecosystem services provided by mesophile hay meadows in mountain pilot areas in the northwest Iberian Peninsula, based on published data and expert opinion, indicates that: (1) meadows have decreased considerably in area over the last 60 years; (2) this reduction has been caused mainly by land-use change and socio-demographic dynamics; (3) loss of meadows is leading to a loss of biodiversity (domesticated species) and a decrease in the supply of strategic ecosystem services such as genetic resources, safe and healthy food products, traditional knowledge or fire risk protection.

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Comparing lamb's meat quality of autochthonous sheep breeds Sarda and Mallorquina under different feeding management systems

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Abstract

In Mediterranean regions, grazing systems are environmentally and socially important, but they are at risk of disappearing due to the lack of profitability. To focus on the higher quality of their production could be a strategy to preserve them. In Sardinia and the Mallorca Islands there are two autochthonous sheep breeds reared on rangeland systems that are genetically correlated. The aim of this study was to compare lamb´s meat quality of these breeds and analyse their relationship with feeding management. Three types of lambs were differentiated according to carcass weight and feeding management in both breeds: Sucking lambs (milk), Light lambs (pasture), Heavy lambs (concentrate). A total of 108 lambs were selected from a data base and fatty acid (FA) profile and chemical composition were analysed. According to lamb types, FA profile was better for Sucking and Light lambs: less saturated FA and higher CLA content. According to breed, Sarda presented lower fat and higher protein content. For the rest of parameters analysed, there was an interaction, Lamb type × Breed presented, in general, better meat quality for the Sarda´s Sucking lamb. Both breeds show an optimal meat quality, in particular in the traditional pasture systems.

Keywords: meat quality, sheep grazing systems, fatty acid profile, chemical composition

Introduction

Sheep farms operating under controlled grazing management systems help maintain the balance of ecosystems by reducing the risk of wildfires, soil erosion and biodiversity loss (Dubeuf, 2011). These pastoral references are in risk of disappearance due to lack of farm profitability. Differentiation of the system that produces high quality animal products for human health represents an important strategy to conserve such pastoral systems (Marrosu *et al.*, 2013). A number of studies reported that both milk (Delgado-Pertiñez *et al*., 2013) and meat (Nardone and Valfrè, 1999) obtained from grazing-based systems offer greater attributes of quality than stall-fed production systems.

Majorca (Spain) and Sardinia (Italy) are two Mediterranean islands where livestock have an important role, both from the socio-economic point of view and from the conservation of their own ecosystems. In these islands, there are two autochthonous sheep breeds genetically correlated (Sanchez and Sanchez, 1987) and raised on rangeland systems grazing natural resources and cultivated pastures under a traditional management: Mallorquina (M) and Sarda (S) breeds. The objective of this study was to characterise attributes of meat obtained from these breeds (fatty acid (FA) profile and chemical composition (CC)) and analyse the relationship between this and the feeding management to improve the conservation of these systems.

Materials and methods

Three lambs types (LT) were differentiated according to carcass weight and feeding management in both M and S breeds: Sucking lambs (Milk), Light lambs (Pasture), Heavy lambs (Concentrate). A total of 108 lambs were selected from a higher data base. Left *Longissimus dorsi* muscle was extracted from each lamb to determine the FA profile and CC. Meat samples were analysed for dry matter, fat, ash, protein in accordance with ASPA indications (1996). Muscle lipids were extracted by means of a chloroform/methanol solution. FA methyl esters were separated, identified and quantified according to Delgado-Pertíñez *et al.* (2013). Data were analysed by GLM (General Linear Model, $\alpha = 0.05$) considering LT, breed and their interaction as fixed effect (SAS Institute, USA).

Results and discussion

Table 1 shows the fatty acid profile and the chemical composition of the meat lambs. No significant differences in chemical composition were observed between LT, whereas some differences were detected between breeds: M lambs had higher ash content (1.54) than S (1.22) which had higher fat and protein content (fat: 1.39 in S lambs and 1.62 in M, protein: 21.06 in S lambs and 20.68 in M). Saturated fatty acids (SFA) were higher in M lambs. A strong effect of LT was found in all parameters under investigation except for monounsaturated fatty acids (MUFA). HC showed the worst fatty acid profile, being lower in both polyunsaturated fatty acids (PUFA) (16.4, 16.7 and 19.3 in HC, LP and SM respectively) and conjugated linoleic acid (CLA) content (0.59, 0.79 and 0.91 in HC, LP and SM respectively) while SM had a better quality profile. The PUFA/SFA index was highest in the S-SM with influence of both breed (higher in Sarda) and lamb type (higher in Milk group) confirming what has been found by Addis *at al.* (2013) that in suckling Sarda lambs measured a PUFA/SFA ratio of 0.53, higher than the minimum suggested value (0.45). These results are in agreement with those found in other work (Diaz *et al.,* 2005), which show that, when the lamb weight increases, the PUFA content decreases. According to Nürnberg *et al.,* 1996, the variation in AG profile associated with age (increase in SFA and decrease in PUFA) is related to the degree of fattening. n-3 content was higher in SM and LP groups of both breeds and the

Table 1. Fatty acid profile (% of total FA) and chemical composition (% fresh weight basis) of Mallorquina (M) and Sarda (S) lambs divided in groups according to their feeding management and breed (SM = sucking lamb; LP = light pasture and HC = heavy concentrate). Values with different letters within rows are significantly different *(P* < 0.005).

	SM		LP		HC		*P*		
	M	S	M	S	M	S	Lamb Type (LT)	Breed (B)	LT × B
Lambs number (n)	30	33	19	9	10	7			
Fatty acid (FA)									
SFA	43.93^{a}	36.50^{b}	43.60^{a}	31.54^{b}	48.59^{a}	39.55^{b}	**	***	ns
MUFA	33.55	33.69	33.97	32.07	32.34	30.71	ns	ns	ns
PUFA	18.52^{ab}	20.04^{a}	18.25^{ab}	15.09^{b}	14.58^{b}	18.14^{ab}	**	ns	*
PUFA/SFA	0.43^{b}	0.56^{a}	0.43^{b}	0.37^{b}	0.30^{b}	0.46ab	**	**	**
CLA total	0.74^{a}	1.08^{a}	0.74^{a}	0.84^{a}	0.46^{b}	0.71^{b}	**	**	ns
n3	5.56^{a}	4.65^{a}	4.35^{a}	4.71^{a}	2.28^{b}	4.06^{ab}	***	ns	*
n6/n3	2.40^{b}	3.54^{b}	3.70^{b}	2.09^{b}	6.72^{a}	3.30^{b}	***	***	***
Chemical composition									
Dry material	24.42	24.30	24.62	24.39	24.47	24.37	ns	ns	ns
Ash	1.41^{b}	1.25^{bc}	1.57^{a}	1.22^{bc}	1.65^{a}	1.18^{c}	ns	***	*
Fat	1.62	1.51	1.58	1.32	1.67	1.34	ns	*	ns
Protein	20.62	21.29	20.92	21.11	20.52	20.80	ns	*	ns

n-6/n-3 index was higher in the M-HC group, whereas it resulted in the optimal range in LP and SM groups (optimal n-6/n-3 ratio of 2.0-2.5, World Health Organization, 2010). In particular, as concern for the LP group, this result could be due to the inclusion of grass in the diet that contains high levels of C18:3, precursor of the n-3 FA (Diaz *et al.,* 2005). Our results agree with previous studies described by Fisher *et al.* (2000) and Diaz *et al.* (2005) for grazing lambs.

Conclusion

Meat from lambs of both breeds had good nutritional quality. Fatty acid profile was better, for both breeds, with lambs fed no concentrate, which is the traditional management in these islands. It is very important from socio-economics and environmental perspectives.

It is necessary to continue researching meat product quality obtained from grazing and to promote its consumption, to improve the profitability of livestock farms and preserve pastoral systems.

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Impact of different forage types on the volatile and sensory properties of bovine milk

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Abstract

The effect of three diets (grass, grass/clover and total mixed ration) on the volatile and sensory properties of bovine milk was assessed over lactation. There was little evidence of direct transfer of terpenes from the diets. Volatile products of lipid oxidation correlated with fatty acid profile based on diet and may have influenced the viscosity perception of milk. Irish assessors always preferred pasteurised milk from grass fed cows, and least preferred milk from total mixed ration diets. In addition, β-carotene content was significantly higher in milks derived from grass or grass/clover and also directly influenced colour perception. The only volatile derived from diet that appeared to influence milk flavour was p-cresol, which has a barnyard aroma and its abundance was lowest in milk derived from total mixed ration and highest in grass/clover. Higher levels of p-cresol in the grass and grass/clover diets are likely due to the rumen metabolism of β-carotene and isoflavones present in white clover, as well as deamination and decarboxylation of more available aromatic amino acids in these diets in comparison to total mixed ration diets. From this analysis, β-carotene, toluene and p-cresol were identified as potential biomarkers for milk derived from pasture.

Keywords: forage, volatiles, sensory, milk, p-cresol

Introduction

The impact of diet on sensory perception of milk and dairy products is unclear because a wide range of factors are involved at farm level (e.g. type of forage, grassland management, forage conservation methods/practices, animal breeds, stage of lactation, health status of the animal), during processing (e.g. heat-treatment, product type, storage fermentation) and because of differences in sensory assessment (e.g. descriptive analysis, discrimination (trained vs untrained assessors) and consumer/affecting testing methods). Factors that potentially influence the flavour of milk and dairy products that derive from diet include compounds that can potentially transfer directly from forage into milk (and subsequently into dairy products produced thereof), or compounds which act as substrates for compounds that eventually culminate in milk or dairy products. Volatile compounds in forage and feed enter milk via two routes: (1) absorption in the digestive tract, i.e. rumen and or intestine before diffusing into the blood and then reaching the mammary gland, (2) pulmonary route, where volatiles diffuse into the air and are inhaled, absorbed into the lungs, enter the blood stream and subsequently, diffuse into the mammary gland (Viallon *et al*., 2000). Previous studies have highlighted that terpenes and carotenoids can potentially impact milk flavour directly as aromatic compounds or indirectly by acting as precursors to other volatile aromatic compounds (Martin *et al.,* 2005; Villeneuve *et al.,* 2013). orage has also been shown to alter the fatty acid profile and protein content of milk (Croissant *et al.,* 2007; Coppa *et al*., 2011; O'Callaghan *et al.,* 2016b), and which may, in turn, alter the sensory perception of milk. The aim of this study was to investigate the sensory quality and aromatic properties of bovine milk (raw and pasteurised) obtained from Friesian cows over a lactation on three distinct feeding regimes: outdoors on a perennial ryegrass pasture, outdoors on a perennial ryegrass/white clover pasture and indoors on total mixed rations.

Materials and methods

Feed Samples: Multiple grass and grass clover samples were collected and pooled from random grazed areas immediately prior to grazing. Representative total mixed ration samples were taken from a bulk supply. Samples were taken at three time points over a season, corresponding to stage of lactation (early, mid and late lactation).

Milk Samples and Processing: Fifty four spring calving Friesian cows were allocated to three groups (n = 18) based on calving date on the Moorepark Dairy Farm (Fermoy, Co. Cork, Ireland). Three feeding systems were compared over a full lactation: Group 1 was housed indoors and fed a total mixed ration diet (TMR), Group 2 was maintained outdoors on perennial-ryegrass only (Grass), while Group 3 was also maintained outdoors on a perennial-ryegrass/white clover pasture (Grass/Clover). In order to obtain a representative sample of milk, the cows in each of the three feeding systems were milked separately into separate 5,000 l insulated tanks. The evening milk was stored at 4 °C overnight, to which the morning milk was added and agitated prior to collection. Bulk milk samples were collected post-morning milking and stored at 4 °C prior to analysis. For the purpose of this study, the different milk types are denoted as G for grass, C for grass/clover and TMR for total mixed ration milks. Where necessary, the prefix 'r' is used to denote raw milk and 'p' to denote pasteurised milk. Each milk sample was homogenised using two stage homogenisation 50 - 150 bar. The milk was pasteurised using a Microthermics® unit heated to 72 °C and held for 15 s then cooled to 4 °C. Each milk sample were transferred at 4 °C to the sterile product outlet and aseptically packed into sterile 1 L glass bottles.

Microbial analyses, β-carotene analyses, milk colour analyses, volatile analyses, sensory evaluation and statistical analysis were all carried out as described in Faulkner *et al.* (2018).

Results and discussion

Twenty two volatiles were present in each feed sample and in all raw milk samples, highlighting the potential of direct transfer from the feed, but also indirectly by rumen metabolism of proteins, lipids, carbohydrates or β-carotene, lipid oxidation, de novo synthesis in the mammary gland or lipolysis. Only six of 40 volatile compounds detected in the raw milk samples by HS-SPME GCMS were statistically ($P < 0.001$) different based on diet (acetic acid, hexanal, 2-butanone, 1-pentanol, dimethyl sulfone and toluene). These volatiles were derived from different potential sources: directly from the feed (acetic acid, 2-butanone), lipid oxidation (hexanal, 1-pentanol), rumen metabolism of β-carotene (toluene), amino acid metabolism in the rumen (dimethyl sulfone, acetic acid), or carbohydrate metabolism (acetic acid, 2-butanone). Some compounds present in the raw milk were not present in their corresponding pasteurised milk samples, suggesting losses or changes due to heat-treatment. Other compounds present in pasteurised milks but absent in the raw milks are likely heat derived. Statistical differences based on diet were also evident in the pasteurised milks at $P < 0.05$ (butanoic acid, pentanal, hydroxy-2(5)H-furanone, 2-furanmethanol and 1-phenylethanol) and at $P < 0.001$ (1-hexadecanol, 1-octadecanol and p-cresol). The potential sources of these compounds may be direct transfer (butanoic acid), de nova synthesis (butanoic acid), Maillard reactions (hydroxy-2(5)H-furanone, 2-furanmethanol), oxidation of fatty acids (hydroxy-2(5)H-furanone, 2-furanmethanol, pentanal, 1-hexadecanol, 1-octadecanol), amino acid metabolism (1-phenylethanol, p-cresol), degradation of β-carotene (p-cresol), and or degradation of isoflavones (p-cresol).

Irish assessors always preferred pasteurised milk from grass fed cows and least preferred milk from total mixed ration diets. 'Colour', 'barnyard aroma' and 'viscosity' were significantly ($P < 0.05$) different based on forage as determined by ranked descriptive analysis. 'Colour' perception correlated with β-carotene content and 'barnyard aroma' with p-cresol content. 'Viscosity' may be associated with differences in the fatty acid content of the milks.

Conclusion

Pasteurisation altered the volatile profile of all milks, with losses of some compounds and the development or augmentation of others. Irish assessors preferred pasteurised milk produced from grass fed cows. Some products of lipid oxidation were evident and related to fatty acid content as influenced by forage but did not influence sensory perception. Tentative associations between feed and some non-terpene volatiles appear to highlight a potential direct transfer to milk in some cases but most differences in volatiles were related to protein/carbohydrate metabolism. β-carotene directly influenced perceived milk 'colour' and p-cresol 'barnyard aroma'. β-carotene, p-cresol and toluene are suggested as potential biomarkers of pasture derived milk.

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Low farm investment and poor herding practices may pose risks to cow welfare in expanding dairy herds

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Keywords: welfare, lameness, investment, roadways, herding

Introduction

Since the abolition of quotas there has been expansion in the Irish dairy industry. Good infrastructure and herding practices are critical to minimise risks to cow welfare in expanded herds (Boyle and Rutter, 2013). The aim of this study was to investigate changes in, and industry opinions about, infrastructure and management on Irish farms in the three years before quota abolition (2012 - 2015).

Materials and methods

In summer 2015, a face to face survey was conducted with farmers (F; n = 115) at two national farming events and cattle vets (V; n = 60) at a national conference. Teagasc dairy advisors completed the questionnaire (A; n = 48) at an 'in-house' training event. Data were analysed in SAS using logistic and mixed procedures. Results are expressed as % of group surveyed.

Results and discussion

The majority (77%) of F increased their herd size. The expected association between larger herds and longer walking distances was confirmed by the positive correlation between the distance to the furthest pasture (884.4 ± 45.2m) and herd size ($r = 0.26$, $P = 0.01$). More F who increased herd size invested in the milking parlour (93.5%) than those that did not expand (6.5%) ($X^2 = 8.3$; $P = 0.004$). This indicates that cow welfare is not likely to be adversely affected by inefficiencies in the milking process in expanded herds. These two groups did not differ in terms of investment in housing or roadways ($P > 0.05$) which raises potential welfare issues for cows, both during the housing period and while at pasture. There was good agreement between V (90.0 ± 3.9%) and A (87.5 ± 4.82%) that the best way to herd cows to the milking parlour is on foot as the cows can walk at their own pace ($P < 0.05$) and is in accordance with best practice in the literature. More than 30% of F reported using a vehicle. On farms where a vehicle was used, herds were larger than on farms where cows were herded on foot (152.7 ± 15.9 vs 99.0 ± 6.1 cows; $P < 0.001$).

Conclusion

The lack of investment in roadways combined with potential for faster herding and longer walking distances in expanded herds may pose risks to cow welfare while at pasture.

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Extended grazing of suckler bulls: effect on the compositional and sensory qualities of beef

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Abstract

In suckler bull beef systems in temperate climates, increasing the proportion of grazed pasture in the animal's diet decreases feed costs. This increases slaughter age which may influence beef quality. The effect of extended grazing on compositional and sensory qualities of bull beef was determined. Fifty six weaned, spring-born, suckler bulls were assigned to: concentrates *ad libitum* (C) until slaughter (CON), or grass silage *ad libitum* plus 2 kg concentrates daily for 123 days, followed by 99 (99G), 162 (162G) or 231 (231G) days grazing and then C until slaughter. The strategy was for CON and 99G to have similar carcass weight and for CON, 162G and 231G to have a similar carcass fat score. Post-slaughter, the *longissimus thoracis* muscle was sampled. Slaughter age averaged 15, 18.5, 22 and 24 months for CON, 99G, 162G and 231G, respectively. Intramuscular fat content was lower ($P < 0.001$) for 99G than for either CON, 162G or 231G, which did not differ significantly. Panellists rated tenderness and overall liking higher ($P < 0.001$) for CON and 162G than for 99G and 231G, which did not differ significantly. Compared to CON, grazing for 162 days did not negatively influence the sensory qualities of bull beef despite the increase in slaughter age.

Keywords: bulls, muscle, composition, sensory characteristics

Introduction

Traditionally, suckler bull beef production was based on the post-weaning provision of concentrate-based diets until slaughter (O'Riordan *et al.*, 2011). O'Riordan *et al.* (2011) showed that introducing a pasture grazing period of 100 days for suckler bulls prior to finishing on concentrates at 19 months of age, decreased the cost of production while Mezgebo *et al.* (2017) showed that this had small effects on the eating quality of beef which were largely due to differences in intramuscular fat (IMF) concentration. Increasing the time at pasture prior to finishing on concentrates would decrease the production costs further but would increase the age at slaughter which may influence consumer preferences and the sensory qualities of beef (Bures and Barton, 2012). The objective of this study was to determine the effect of increasing the grazing period to eight months prior to finishing on concentrates (to achieve a carcass fatness similar to that achieved by the intensively concentrate-fed bulls) on the chemical composition and sensory characteristics of beef. It was hypothesized that extending the grazing period to a full season, and its associated increase in slaughter age, would negatively influence the quality of beef, particularly sensory tenderness.

Materials and methods

Fifty six spring born (mean birth date 8 March) Charolais and Limousin sired weaned suckler bulls were purchased at approximately eight months of age and average initial weight of 372 kg. They were acclimatised to slatted floor accommodation and offered grass silage *ad libitum* plus 2 kg head^{-1} day^{-1} of a barley-based concentrate before random assignment (1 December) to four treatments (14 animals per treatment) balanced for sire and dam breed, birth date and initial liveweight. The four treatments were:

(1) *ad libitum* concentrates (870 g kg^{-1} rolled barley, 60 g kg^{-1} soya bean meal, 50 g kg^{-1} molasses and 20 g kg^{-1} minerals/vitamins) plus grass silage (dry matter digestibility 700 g kg^{-1}) *ad libitum* until slaughter (C), (2) grass silage *ad libitum* plus 2 kg concentrate daily during the winter (123 day duration) (GS) followed by 99 days at pasture and then an indoor finishing period on C until slaughter (99G), (3) GS followed by 162 days at pasture and then an indoor finishing period on C until slaughter (162G) and (4) GS followed by 231 days at pasture and then an indoor finishing period on C until slaughter (231G). The strategy was for CON and 99G to have similar carcass weight and for CON, 162G and 231G to have a similar carcass fat score. The duration of the concentrate finishing periods were 201, 71, 120 and 121 days for C, 99G, 162G and 231G bulls, respectively. The bulls were slaughtered at a commercial slaughter plant (Kepak Group, Clonee, Co. Meath, Ireland). Post slaughter, carcasses were weighed and graded for conformation and fatness (15 point scale, 1 = poorest/lowest). Samples of the *longissimus thoracis* (LT) muscle were collected at 48 h post-mortem. A detailed description of the compositional (48 h post-mortem) and sensory (14 d post-mortem) analyses methods are given in Mezgebo *et al.* (2017). A 10 person trained taste panel assessed each steak using 8 point category scales for tenderness (1 = extremely tough to 8 = extremely tender), juiciness (1 = extremely dry to 8 = extremely juicy), beefy flavour and abnormal beef flavour intensities (1 = extremely weak to 8 = extremely strong). Data were subjected to analysis of variance using the General Linear Model procedure of SPSS (IBM SPSS Statistics Version 20) where the production systems were regarded as fixed factors. Assessor and session were also regarded as fixed factors when analysing the sensory panel data.

Results and discussion

Production, carcass and meat quality traits are summarised in Table 1. Unless stated otherwise, differences were statistically significant ($P < 0.05$). Age of bulls at slaughter increased in order: C, 99G, 162G and 231G. Slaughter and carcass weights were lower for C and 99G (which did not differ significantly) than for 162G bulls, which in turn was lower than for 231G bulls. Fat score was lower for 99G than for 162G, 231G and C bulls, which did not differ significantly. To meet many market specification carcass fat levels need to be ≥ 6 on 1-15 scale. The lower IMF content for the 99G bulls compared to the 162G and 231G bulls could be attributed to the shorter duration of the concentrate finishing period (71 days compared to 120 and 121 days respectively). Tenderness was higher for C and 162G (which did not differ significantly) than for 99G and 231G, which did not differ significantly. Juiciness was higher for 231G than for C and 99G (which did not differ significantly) but similar to 162G, which in turn was

Table 1. Animal and *longissimus thoracis* muscle characteristics in bulls raised on either concentrate-based system (C) or pasture-based systems incorporating 99 days (99G), 162 days (162G) or 231 days (231G) of grazing period prior to finishing on a concentrate-based diet.

	Production system					
	C	99G	162G	231G	sem[1]	Significance[2]
Age at slaughter (months)	15.0^{a}	18.3^{b}	22.0^{c}	24.5^{d}	0.20	***
Carcass weight (kg)	379^{a}	387^{a}	438^{b}	475^{c}	8.09	***
Fat score	8.4^{b}	6.6^{a}	8.2^{b}	9.0^{b}	0.29	***
Intramuscular fat (g kg^{-1})	23.2^{b}	10.2^{a}	20.8^{b}	19.9^{b}	1.69	***
Tenderness	4.6^{b}	4.2^{a}	4.6^{b}	4.3^{a}	0.09	***
Juiciness	4.8^{a}	4.8^{a}	5.0^{ab}	5.1^{b}	0.07	**
Beefy flavour	4.6	4.5	4.5	4.5	0.06	ns
Abnormal flavour	2.3	2.4	2.4	2.5	0.07	ns
Flavour liking	5.5^{b}	5.1^{a}	5.2^{ab}	5.1^{a}	0.08	**
Overall liking	5.0^{c}	4.6^{a}	4.9^{bc}	4.7^{ab}	0.08	***

[1] Sem = standard error of the mean.

[2] ns = not significant, ** = $P < 0.01$, *** = $P < 0.001$.

similar to C and 99G. Flavour liking was higher for C than for 99G and 231G (which did not differ significantly) but similar to 162G, which in turn was similar to C and 99G. Overall liking was higher for C than for 99G and 231G (which did not differ significantly) but similar to 162G, which in turn was similar to 231G. The differences in sensory tenderness, juiciness, flavour liking and overall liking scores between the treatments could mainly be attributed to the variations in age at slaughter, IMF content and/or their combined effects. The lower tenderness, flavour liking and overall liking scores for the 231G bulls compared to the C and 162G bulls could mainly be attributed to their older age at slaughter and possibly higher collagen cross-link content as the IMF content was similar for each group. The lower flavour liking and overall liking scores of the 99G bulls compared to the C bulls could mainly be attributed to their lower IMF content. The favourable juiciness scores for both 162G and 231G bulls and the higher juiciness scores for the 231G bulls compared to the 99G bulls can possibly be related to their older age at slaughter as beef from older and fatter animals is perceived to be juicier than beef from younger and leaner animals (Baublits *et al.*, 2006).

Conclusion

Extending the time at pasture to 162 days prior to finishing indoors on high energy concentrate diet, resulted in a beef with a sensory quality similar to that from intensively concentrate fed bulls. Grazing for 231 days led to beef with poorer sensory characteristics compared to intensively concentrate fed bulls. These sensory attributes were similarly adversely affected by a shorter finishing period on concentrates (71 vs ≥ 120 days), even when bulls were slaughtered younger which is likely due to the lower IMF concentration.

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Colour and sensory characteristics of *longissimus* muscle from grass-fed or concentrate-fed heifers

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Abstract

'Grass-fed' beef commands a premium price in some markets based on perceived differences in meat appearance and sensory characteristics compared to regular beef. These characteristics were compared for beef from a novel 'grass-fed' production system and from a concentrate-based production system. Following weaning at eight months of age, spring-born suckler Angus heifers (n = 15/treatment) were fed grass silage indoors during the winter, followed by grazed grass (Grass) or concentrates *ad libitum* (Conc) indoors. Cattle were slaughtered at a target carcass weight of 260 kg. Post slaughter, the *longissimus* muscle was aged for 14 d (2 °C). Colour was then recorded and sensory characteristics determined by a trained sensory panel. Actual mean carcass weight was 264 and 258 kg for Conc and Grass ($P > 0.05$), respectively. Muscle pH was similar for both treatments groups (pH 5.57) while muscle from Conc was brighter (higher L*) than muscle from Grass (45.5 vs 43.7, $P < 0.05$). Muscle from Grass had a higher vegetable/grass flavour ($P < 0.05$) than muscle from Conc (4.9 vs 3.4) but there was no difference in the other sensory characteristics measured. These differences in muscle colour and sensory characteristics are unlikely to be relevant to the consumer.

Keywords: grass, beef, colour sensory characteristics

Introduction

Increasingly, consumers are interested in the provenance of their food and pasture-based systems have come to be regarded by some as more environmentally and animal welfare friendly alternatives to intensive/feedlot systems of production (Li *et al.*, 2016). Animal products from such systems, for example, those labelled as 'grass-based', can command a price premium based on perceived differences in appearance and sensory characteristics compared to regular beef. While there is some comparative information on the quality of beef from cattle that grazed for a period before or during the finishing period (Baublits *et al.,* 2006), there is little information on the quality of beef from cattle that comply with a definition of 'never receiving concentrates during life'. Accordingly, the objective of this study was to compare the appearance and sensory characteristics of beef from a novel 'grass-fed/concentrate-free' production system with that from a concentrate-based production system.

Materials and methods

Thirty spring born Angus-sired (Angus-sired dams) weaned heifers were purchased at approximately eight months of age with an average initial weight of 297 kg after verification that they had never received concentrates to date. They were acclimatised to slatted floor accommodation and offered grass silage *ad libitum* before random assignment (1 December) to two treatments (15 animals per treatment) balanced for birth date and initial weight. The treatments were: (1) *ad libitum* concentrates (870 g kg^{-1} rolled barley, 60 g kg^{-1} soya bean meal, 50 g kg^{-1} molasses and 20 g kg^{-1} minerals/vitamins) plus grass silage (dry matter digestibility 650 g kg^{-1}) *ad libitum* indoors until slaughter (Conc), (2) high digestibility (dry matter digestibility 750 g kg^{-1}) grass silage *ad libitum* plus a mineral supplement daily during the winter (123 day duration) and then rotationally grazed a perennial ryegrass-dominant pasture until slaughter

(Grass). The heifers were slaughtered at a commercial slaughter plant (Kepak Group, Clonee, Co. Meath, Ireland) when they reached a group mean live weight to yield a mean target carcass weight of 260 kg. Post slaughter, carcasses were weighed and graded for conformation and fatness (15 point scale, 1 = poorest/lowest). At 48 h post-mortem, subcutaneous fat colour (i.e. L^*, a^*, b^* colour coordinates) was measured using a Miniscan XE Plus (Hunter Associates Laboratory Inc., Virginia, USA). The pH of the *longissimus thoracis* (LT) muscle was then recorded, the muscle removed, vacuum packaged and aged (2 °C) for a further 12 days. The colour of muscle was then recorded after 1 h exposure to air and samples frozen for subsequent analysis. A detailed description of the compositional and sensory analysis procedures is given by Keady *et al.* (2017). A 10-person trained taste panel assessed each steak using 100 mm line scales (1 = poorest, 100 = best), for tenderness, juiciness, beefy flavour and abnormal beef flavour intensities and for specific flavour notes. Data were subjected to analysis of variance using Genstat with a model that had block and production systems as main effects. Assessor and session were included as sources of variation when analysing the sensory panel data.

Results and discussion

Carcass and meat quality traits are summarised in Table 1. Conc heifers were slaughtered on 8 June while Grass heifers were slaughtered on 11 November. Mean carcass weight for Conc and Grass did not differ, as planned. Neither carcass fat nor conformation scores differed between Conc and Grass. The subcutaneous fat was more yellow (higher b* value) ($P < 0.05$) for Grass than Conc which would preclude Grass carcasses from some Mediterranean markets for Irish beef (Dunne *et al.,* 2004). The lower intramuscular fat content for the Grass heifers compared to Conc heifers despite the similar carcass fat score could be attributed to the lower energy density of grazed grass compared to the concentrate ration and consequent slower growth rate.

Table 1. Carcass and *longissimus thoracis* muscle characteristics in heifers raised on either a concentrate or 'all' grass-based system (Grass).

	Production system			
	Concentrate	**Grass**	**Sed[1]**	**Significance[2]**
Carcass weight (kg)	258	264	6.4	ns
Carcass fat score	10.1	10.6	0.49	ns
Carcass conformation score	6.9	6.9	0.36	ns
Carcass fat colour				
Lightness (L*)	71.2	70.0	0.82	ns
edness (a*)	9.2	8.5	0.46	ns
Yellowness (b*)	16.6	17.9	0.36	**
Muscle pH	5.56	5.58	0.023	ns
Muscle colour				
Lightness	45.5	43.7	0.607	*
Redness	16.7	17.2	0.38	ns
Yellowness	13.0	12.8	0.39	ns
Intramuscular fatty acids (g kg^{-1})	61.9	44.8	2.311	*
Muscle sensory characteristics				
Tenderness	43.7	46.0	2.58	ns
Juiciness	46.4	47.8	2.33	ns
Beefy flavour	54.8	51.7	1.82	ns
Abnormal flavour	9.3	10.9	1.53	ns
Vegetable/grass	3.4	4.9	0.75	*
Overall liking	47.4	46.0	2.30	ns

[1] Sed = standard error of difference.

[2] ns = not significant, * = $P < 0.05$, ** = $P < 0.01$.

Despite the difference in age at slaughter (five months), there was no difference between meat from Conc and Grass in ratings for tenderness, juiciness and overall liking (when cooked to an internal temperature of 74 °C). McElhinney *et al.* (2017) reported differences in the intramuscular fatty acid profile of beef from Conc and Grass that were qualitatively similar to the literature. Other than the vegetable / grassy note for which meat from Grass was rated higher ($P < 0.05$), there was no difference between meat from Conc or Grass in ratings for greasy, bloody, livery, metallic, bitter, sweet, rancid, fishy, acidic, cardboard or dairy or overall beefy flavour and abnormal flavour.

Conclusion

Producing heifers on a lifetime grazed grass or grass products diet resulted in beef that was not suitable for markets that have a requirement for white carcass fat. The scale of the difference in muscle colour from the two production systems is unlikely to be of commercial relevance. Under the conditions of this experiment, there was no evidence of a difference in the sensory characteristics of beef from 'grass-fed' and concentrate production systems. The profitability of both production systems is under investigation.

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Farmers' perceptions on the apple orchard silvopasture in Galicia (NW Spain)

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Keywords: agroforestry, interviews, woody vegetation, pasture, knowledge

Introduction

In Europe, the adoption of agroforestry practices by farmers is limited. Therefore, it is important to understand how farmers perceive agroforestry practices to promote their adoption (Rois-Díaz *et al.*, 2017). The aim of this study was to understand the knowledge that farmers have on apple orchard silvopasture in Galicia (NW Spain) through an analysis of farmer qualitative interviews.

Materials and methods

Qualitative interviews were conducted with farmers in Galicia. Farmers were randomly selected after stratification into two groups: farmers implementing conventional agriculture and farmers implementing apple orchard silvopasture. There were two types of questions in the interviews: 'simple' or closed format questions, and 'complex' or open format questions. More information on the interviews can be found in Rois-Díaz *et al.* (2017).

Results and discussion

The most common definition identified by farmers, for both agroforestry and non-agroforestry farmers, was that silvopasture is a combination of trees and animals. Most of the farmers did not establish silvopastoral practices on their apple orchards mainly due to a lack of technical knowledge or due to time constraints as a consequence of part-time employment. Taking into account these results, it would be beneficial to establish and/or reinforce networks among farmers in order to facilitate the flow of information because the most innovative farmers can experiment themselves with agroforestry practices.

Conclusion

In Galicia, farmers do not establish silvopastoral practices mainly due to a lack of technical knowledge, in spite of recognising the benefits of silvopasture in their orchards. It is necessary to increase the agroforestry knowledge among the farmers through the information activities and the establishment of innovation networks.

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The effect of cow feeding system on the composition and quality of milk and dairy products

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Abstract

This study investigated the effects of pasture versus indoor total mixed ration (TMR) feeding systems on the chemical composition, quality characteristics and sensory properties of raw milk, sweet cream butter and full fat cheddar cheese. Fifty four multiparous and primiparous Friesian cows were divided into three groups (n = 18) for an entire lactation. Group 1 was housed indoors and fed a TMR diet of grass silage, maize silage and concentrates, Group 2 was maintained outdoors on perennial ryegrass (*Lolium perenne* L.) only pasture (GRS), while Group 3 was also maintained outdoors on perennial ryegrass/white clover (*Trifolium repens* L.) pasture. Milk from pasture-based systems had greater fat and protein contents and improved protein quality compared with milk from TMR. Pasture feeding had a beneficial impact on the fatty acid (FA) profile of milk and dairy products with increased concentrations of beneficial nutrients such as Omega 3 FAs, conjugated linoleic acid, vaccenic acid and reduced levels of palmitic acid, Omega 6 FAs and thrombogenecity index score than TMR. Alterations to the FA content resulted in significant rheological differences of butter and Cheddar cheeses including textural properties and colour. Pasture derived products were shown to have significantly greater contents of β-carotene, imparting a characteristic yellow colour on products. Sensory analysis revealed a preference for dairy products derived from the pasture-based systems compared with the TMR-based system.

Keywords: pasture, TMR, milk, dairy, fatty acids, quality

Introduction

Ireland has a somewhat unique low input pasture-based dairy system where its temperate climate and soil type provides ideal conditions for grass growth and cows spend the majority of their lactation grazing outdoors. The use of a total mixed ration (TMR), high-input indoor feeding system is widely used in the United States, parts of Europe and the southern hemisphere (van Arendonk and Liinamo, 2003; Barberg *et al.*, 2007). A TMR diet typically includes a formulated mix of forages, grains, minerals and vitamins designed to enable the cow to achieve increased DM intake, maximum performance and increased milk yield. However, by its nature, a TMR system is an expensive and high-input enterprise, requiring specialised machinery and housing. There is currently a consumer perception that milk from cows on pasture is more natural than that from more conventional indoor ration feeding systems (Verkerk, 2003). However, there is limited information available to substantiate this, particularly from an Irish grazing system perspective. The purpose of this study was to examine the effects of cow feeding systems on the composition, quality and sensory characteristics of raw milk, butter and Cheddar cheese.

Materials and methods

Fifty four spring calving Friesian cows were allocated to three groups (n = 18) at the Teagasc, Animal and Grassland Research and Innovation Centre, Moorepark, Fermoy, Co. Cork, Ireland. Three feeding systems were compared over a full lactation; Group 1 was housed indoors and fed a total mixed ration diet (TMR), Group 2 was maintained outdoors on perennial ryegrass (*Lolium perenne* L.) only pasture (GRS) while Group 3 was also maintained outdoors on a perennial ryegrass/white clover (*Trifolium repens* L.) pasture (CLV). Cows on the TMR were offered, on a DM basis, 7.15 kg of grass silage, 7.15

kg of maize silage and 8.3 kg concentrates daily. Cows on the pasture-based systems were offered ~ 18 kg DM day^{-1} (> 4 cm). The CLV sward contained approximately 20% white clover. In order to obtain a representative sample of milk, the cows in each of the three feeding systems were milked separately into designated 5,000 l refrigerated tanks. The evening milk was stored at 4 °C overnight, to which the morning milk was then added to and agitated prior to collection. Bulk milk samples were collected post-morning milking weekly throughout lactation and stored at 4 °C prior to analysis. Bulk milk samples were also collected for the production of mid-lactation sweet cream butter and at the beginning of late-lactation for lactation Cheddar cheese. Milk macro composition analysis was carried out using a Foss FT6000 milkoscan, and nitrogen fractions were analysed using the Kjeldahl method. Triglyceride fatty acid (FA) analysis was carried out using gas chromatography with flame ionisation detection (GC-FID). Butter samples were analysed for triglyceride content, texture profile analysis, β -carotene, colour, thermal properties, volatile and sensory analysis. Cheeses were analysed for triglyeride content, proteolysis, texture profile analysis, colour, β –carotene, volatile and sensory analysis. For further info on the materials and methods please see O'Callaghan *et al.* (2016b), O'Callaghan *et al.* (2016a) and O'Callaghan *et al.* (2017).

Statistical analysis of milk data, butter and Cheddar cheese data collected over time was carried out using Between and Within subjects repeated measures ANOVA, examining the effect of different feeding systems (TMR, GRS and CLV) (treatment) throughout lactation, ripening or storage period (time). For Butter and Cheddar cheese data collected at one time point, Shapiro-Wilks test was performed to test for normality followed by a One Way ANOVA with post hoc Tukey test. P values < 0.05 were considered significant. Statistical analysis was performed using SPSS v 18.

Results and discussion

The GRS feeding system produced milk with greater concentrations of fat (4.65 vs 4.39%) and protein (3.65 vs 3.38%) compared to TMR system. Moreover, GRS feeding system produced milks with improved quality protein with increased true protein concentrations compared to TMR system (3.46 vs 3.19%). The inclusion of CLV appeared to produce milk with comparable compositional concentrations to that of GRS. However, CLV had significantly ($P < 0.05$) greater non-protein nitrogen (NPN) than that of GRS and TMR. Pasture feeding appeared to beneficially alter the nutritional status of milks with greater than two fold increases in total concentration of conjugated linoleic acid (CLA) c9t11, offering further confirmation to previous studies that revealed an association between increased milk CLA and fresh grass feeding (Kelly *et al.*, 1998). Pasture feeding systems resulted in significantly greater contents of Omega 3 FAs and significantly lower contents of Omega 6 FAs than that of TMR milk, which also had a significantly greater thrombogenic index (calculated according to Ulbricht and Southgate (1991)) than that of pasture derived milks. Feeding system resulted in significant differences in FA compositions of sweet cream butter. Such alterations in the FA compositions contributed to significant differences in textural, thermal, sensory and volatile properties of butters. Pasture-derived (GRS and CLV) systems produced butters with improved nutritional aspects, including lower thrombogenecity scores and significantly greater concentrations of CLAc9t11 and β-carotene. Sensory panellist data revealed significantly greater scores for GRS derived butter in several attributes including 'liking' of appearance, flavour and colour. Volatile analysis of butters by gas chromatography mass spectrometry (GC-MS) revealed 25 different compounds from each of the butters, five of which differed significantly based on feeding system, including acetone, 2-butanone, 1-pentenol, toluene and β-pinene. The nutritional composition of Cheddar cheese was also improved through pasture-based feeding systems with significantly ($P < 0.05$) lower thrombogenicity index scores and a greater than two-fold increase in the concentration of vaccenic acid and CLA c9t11 ($P < 0.05$), while TMR derived cheeses had significantly greater palmitic acid content ($P < 0.05$). Pasture derived Cheddar cheeses were shown to have significantly greater Omega 3 FA content while TMR cheeses had significantly greater Omega 6 FA content. The consumption of CLA has been associated with several potential health benefits, with recommended intake of 0.8 g CLA d^{-1} to attain such benefits based on animal models of therapeutic doses (Siurana and Calsamiglia, 2016). Adjusting for the mean fat contents of cheeses in this study, 100 g of Cheddar cheese from TMR would provide 0.15 g of CLAc9t11, 100 g of CLV cheese would provide 0.35 g of CLAc9t11, whereas 100 g of GRS derived Cheddar cheese would provide 0.44 g of CLAc9t11. Such alterations in the FA profile resulted in pasture derived cheeses having reduced hardness scores at room temperature. Both feeding system and ripening time had a significant effect on the volatile and sensory profile of the Cheddar cheeses.

Conclusion

In conclusion, this study has demonstrated the benefits of pasture derived feeding systems for production of milk, butter and Cheddar cheeses with enhanced nutritional and rheological quality compared with a TMR feeding system. For further information on these studies see O'Callaghan *et al.* (2016b), O'Callaghan *et al.* (2016a), O'Callaghan *et al.* (2017) and (Faulkner *et al.*, 2018).

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Associating cow characteristics with sub-optimal mobility in dairy cows in Irish pasture-based systems

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Abstract

Sub-optimal mobility in dairy cows has significant economic and environmental consequences which have yet to be extensively researched or quantified for pasture-based systems. While traditionally lameness was defined by a requirement to treat individual cows, sub-optimal mobility is now being used to identify lameness in pasture-based systems. Compared to cows in confinement systems, cows in pasture-based systems are exposed to different types of mobility issues. While cows in confinement systems are at risk to infectious hoof disorders such as mortellaro, cows in pasture-based systems are vulnerable to non-infectious hoof disorders, such as overgrown claws and whiteline disease. To precisely quantify sub-optimal mobility in terms of its impacts economically and environmentally, a clear understanding of the characteristics of a sub-optimal mobility cow is required. Mobility score (MS), hoof disorders prevalence and body condition score (BCS) were recorded for 7,649 dairy cows and were examined in this study in order to characterise a cow with sub-optimal mobility. Cows with more severe type hoof disorders were significantly more at risk to having sub-optimal mobility; this study shows that both hoof disorders and BCS are useful indicators of sub-optimal mobility in dairy cows.

Keywords: mobility score, locomotion, pasture-based

Introduction

Sub-optimal mobility in dairy cows is considered by the dairy industry worldwide to be among the most significant challenges (Huxley, 2012), and the third most important health-related economic loss, after fertility and mastitis (Bruijnis *et al.*, 2010; Huxley, 2013). Sub-optimal mobility can be broadly defined as abnormal gait which causes a deviation from the optimal walking pattern of a cow. The main cause of sub-optimal mobility is hoof disorders, which are responsible for 92% of cases (Murray *et al.*, 1996). The severity of sub-optimal mobility can vary greatly from slight deviations from normal gait and walking pattern to severe immobility and inability to bear weight on a limb. As a result of this difficulty in defining sub-optimal mobility/lameness, it is not surprising that there is high variability in the reported incidence and production losses. In order to fully understand sub-optimal mobility, it is essential to have a clear understanding of what the normal mobility of a dairy cow is defined as. For the most part, lameness is predominantly defined based on a locomotion/mobility score (MS) where the most used definition and scoring method is that of (Sprecher *et al.*, 1997). Using Sprecher's method, lameness is defined as having a locomotion score of ≥ 2 based on a 5 - point scale, where a score of 1 is optimal locomotion and a score of 5 is extremely lame. For this study, the DairyCo mobility scoring method (http://tinyurl.com/yc8blc9e; accessed 27 July 2017) was used. The DairyCo mobility scoring tool is a 4 point scale ranging from 0 to 3, where 0 describes a cow with optimal mobility and 3 describes a very poor mobility (classified as severely lame). This study aims to characterise sub-optimal mobility, by using lesion prevalence and BCS to predict MS.

Materials and methods

An Irish Department of Agriculture Food and the Marine funded study across spring calving dairy herds with the objective of collecting animal health data was used as the data source. There were 7,649 cows included in this data set, from 52 spring-calving pasture-based dairy farms in the south of Ireland. Included in this dataset is a unique cow identifier tag number, MS, BCS, type and location of hoof disorder, (records for both non lame and lame cows, and includes the specific location of the lesion(s)), and photos linked to individual cows foot lesions were collected. For the lesions data, severity scores are also included, whereby for example in the case of overgrown claw, 0 refers to a cow with no evidence of an overgrown claw, 1 refers to a cow with a very minor overgrown claw, 2 refers to a cow with a moderate overgrown claw and 3 refers to a cow with a very severe overgrown claw. Cows were recorded for bruised claw(s) and scored from 0 to 5, and cows with evidence of mortellaro were scored only 0/1, i.e. absent or present.

For the statistical analysis, the effects of independent variables on MS were assessed using a forward stepwise regression approach. Output variables were analysed with logistic regressions as multinomial (three output categories). Included in the model used to predict cow MS to be 0, 1, 2 or 3 were lesion presence and severity/absence (denoted by a 0 if absent and > 0 if present), and cow BCS. Analyses were performed using R statistical software (R Development Core Team, 2009; functions multinomial logistic regressions).

Results and discussion

As presented in Table 1, 51.6% (3950 cows) of the 7649 cows were recorded to have some form of overgrown claw (ranging from severity score 1 to 3). The impact of a cow having an overgrown claw severity score 1 on MS was not significantly different ($P > 0.05$) to having a score of 0 (except when comparing MS 1 to 0). A cow with an overgrown severity score 2 or 3 was different compared to a cow having a severity score of 0 at all levels of MS ($P < 0.05$). A cow with an overgrown claw severity score

Table 1. ORs for the multinomial logistic regression model used to predict the mobility score (MS) 0, 1, 2 or 3 based on lesion absence/severity if present. Prediction relied on 7,649 cows scored for lesion presence/lesion severity score and BCS.[1]

Risk factor	Category %	OR Spring Mobility Score 1 v 0	OR Spring Mobility Score 2 v 0	OR Spring Mobility Score 3 v 0
Overgrown 0	48.35%	1	1	1
Overgrown 1	35.53%	1.19*(816)	1.08‡(65)	1.95‡(15)
Overgrown 2	13.13%	1.64***(358)	2.77***(52)	4.23***(10)
Overgrown 3	2.99%	2.65***(77)	18.00***(46)	66.05***(21)
Spring BCS		0.99***	0.98***	0.97***
Whiteline 0	51.24%	1	1	1
Whiteline 1	16.55%	1.06‡(347)	1.12‡(32)	0.89‡(5)
Whiteline 2	14.25%	1.28*(341)	1.20‡(29)	1.07‡(5)
Whiteline 3	10.22%	1.46***(256)	2.51***(39)	2.84***(9)
Whiteline 4	5.43%	1.96***(156)	4.51***(32)	8.87***(15)
Whiteline 5	2.39%	2.42***(72)	8.67***(23)	10.84***(6)
Spring BCS		0.99***	0.98***	0.97***
Mortellaro 0	97.33%	1	1	1
Mortellaro 1	2.67%	1.40*(61)	5.30***(24)	15.68***(14)
Spring BCS		0.99***	0.98***	0.97***

[1] OR = odds ratio, BCS = body condition score. ***, **, *, ‡ OR is significantly or tends to be different from 1 ($P < 0.001$, 0.01, 0.05, 0.10). The figure after each lesion refers to the severity of the lesion, i.e. overgrown 0 = no overgrown claw, overgrown 4 = severely overgrown claw. (_) = number of cows.

of 2 had a risk ratio of 4.23 while a severity score 3 had a risk ratio of 66.05 to have a MS 3 versus 0. For whiteline disease, 48.8% (3,735 cows) of the 7,649 cows were recorded to have some form of whiteline disease (ranging from severity score 1 to 5). The impact of a cow having a whiteline disease severity score of 1 or 2 on MS was not significantly different ($P > 0.05$) to having a score of 0 (except when comparing whiteline disease severity score 2 to MS 1 to 0). A cow with a whiteline disease severity score of 3, 4 or 5 was different compared to a cow having a severity score of 0 at all levels of MS. A cow with a whiteline disease severity score of 3 had a risk ratio of 2.84 while a severity score 4 has a risk ratio of 8.87, and a cow with a severity score 5 had a risk ratio of 10.84 to have a MS 3 versus 0. Not surprisingly, in a pasture-based system, the number of cows recorded to have some claw(s) affected by mortellaro was quite low with 2.7% (204 cows) of the 7,649 cows recorded to have mortellaro on at least one claw. Of the 204 cows recorded to have at least one claw affected by mortellaro, their risk ratio was 15.68 to have a MS 3 versus 0. Across all hoof disorder types, BCS always had a significant impact on MS. The results presented in Table 1 indicate a decrease in BCS was associated with a MS > 0. Based on the risk ratios, however, this impact is quite small and it may be hard to predict MS based on BCS in future models. This is due to the relatively small variation between each cow's BCS. Based on this analysis and the definition of MS, it is now possible to determine the performance effects of individual animals and their MS.

Conclusion

This analysis confirms an association between MS and more severe type hoof disorders. The results indicate that lesion presence and severity, as well as BCS, are relevant predictors of MS. Based on lesion presence, severity and BCS, the results also indicate the thresholds wherein MS is likely to be sub-optimal in dairy cows in pasture-based systems.

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Microbial quality of milk from grass based production systems and impact on milk powder quality

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Abstract

The microbial quality of bovine milk, produced on a pasture-based system on 67 dairy farms, and its influence on milk powder quality were evaluated. The diet of the cows consisted mainly of perennial ryegrass with an additional 2.0 kg DM cow^{-1} day^{-1} of concentrates. Milk was sampled from farm bulk tanks, as well as from the 11 collection tankers, whole milk (WMS) and skim milk (SMS) silos. Skim milk powder (SMP) was also sampled. The average total bacterial count (TBC) for the farm milk samples was 3.78 ± 0.08 $\log_{10}$ cfu ml^{-1}, which was similar to that observed in the tankers (3.90 ± 0.41 $\log_{10}$ cfu ml^{-1}) and increased in the WMS (5.89 ± 0.02 $\log_{10}$ cfu ml^{-1}). Pasteurisation decreased TBC (SMS: 2.61 ± 0.20 $\log_{10}$ cfu ml^{-1}), while evaporation and drying resulted in further reductions of TBC in SMP (2.36 ± 0.09 $\log_{10}$ cfu g^{-1}). Thermal processes were not efficient in reducing thermoduric bacterial counts (LPC), which did not vary greatly from farm (0.90 ± 0.11 $\log_{10}$ cfu ml^{-1}) to SMS (1.85 ± 0.10 $\log_{10}$ cfu ml^{-1}). In conclusion, milk of good microbial quality can be produced from grass-based systems, resulting in high quality milk powder.

Keywords: milk quality, milk powder, pasture-based systems, microbiological quality

Introduction

Ireland is the tenth largest dairy exporter in the world, supplying dairy products to 130 countries. The Irish industrial milk production is currently expanding due to the end of the milk quotas and to the increase in demand for dairy products worldwide. The maintenance of high milk quality is essential to hold market share and produce dairy products in accordance with specific quality parameters. On Irish dairy farms, pasture-based seasonal calving is the main milk production system, coordinating the peak of the lactation period and milk production with grass growth peak. Farming systems that are pasture-based can contribute to the production of milk with high fat content (due to a diet rich in fibre) and high protein content. Such milk is rich in fatty acids, vitamins and volatile compounds (flavours, terpenes) favourable to human nutrition and health. In this study, the microbiological quality and composition of milk produced from pasture-based systems on 67 commercial dairy farms were evaluated and monitored throughout the milk powder manufacturing process, and the effect on the final product quality was evaluated.

Materials and methods

To undertake the manufacturing process within the factory, a minimum quantity of milk was required (296,003 l), which was supplied by a total of 67 dairy farms during the mid-lactation period (May, 2016). The dairy farms that participated in this study were located in the Kilkenny and Waterford regions of Ireland. The diet of the cows on the farms (Holstein-Friesian, 120 DIM) consisted mainly of perennial ryegrass with on average an additional 2.0 kg DM cow^{-1} day^{-1} of concentrates. The average milk volume collected from each farm was 4,418 l, which was stored in bulk tanks for an average of 48 h prior to tanker collection. Collection tankers (11) transported the milk from the farms (approximately 6 farms / tanker) to a commercial skim milk powder factory and the milk collected was stored in the whole milk silo (WMS) for approximately 5.5 h at 4.6 °C. Milk was then pasteurised (high temperature / short time treatment), cream was separated and skim milk was stored in the skim milk silo (SMS). The skim milk underwent evaporation and a spray-drying process to produce skim milk powder (SMP) (21,940 kg). Milk samples were collected from the top inlet of the 67 farm bulk tanks, collection tankers (11) and the WMS and SMS. During the start, middle and final stages of the spray dryer run, 9 × 25 kg bags of powder were collected. A representative sample was collected from each bag (300 g) and reconstituted using deionised water (1:10 dilutions). All samples were tested for total bacterial count (TBC), psychrotrophic (PBC), proteolytic (PROT), thermoduric (Laboratory pasteurisation count – LPC), thermophilic (THERM), presumptive *Bacillus cereus* (BAC) and sulphite-reducing *Clostridia* (SRC) bacterial counts, as well as fat, protein and lactose contents were also measured in the samples. Somatic cell count (SCC) was measured in all samples, except in the SMP samples.

Results and discussion

The TBC and PBC levels in the farm bulk tank milk samples varied from 2.48 to 4.97 $\log_{10}$ cfu ml^{-1} and from 2.84 to 4.67 $\log_{10}$ cfu ml^{-1}, respectively. The TBC levels were below the European limit (TBC: 5.00 $\log_{10}$ cfu ml^{-1}, EC no 853/2004) and below the typical limit applied by some Irish milk processors (4.70 $\log_{10}$ cfu ml^{-1}). Twelve farms had PBC levels higher than the European limit (PBC: 4.22 $\log_{10}$ cfu ml^{-1}), possibly due to the milk storage temperature within the bulk tanks, as low temperatures are favourable for the growth of psychrotrophs. The average PROT was below the limit suggested by Vyletelova *et al.* (2000) (4.65 $\log_{10}$ cfu ml^{-1}), at which proteolytic bacteria starts to produce high levels of heat-resistant enzymes. The LPC levels were below typical Irish milk processor specifications and varied from 2.70 to 3.00 $\log_{10}$ cfu ml^{-1}. Milk of good microbiological quality was produced on-farm, given that TBC, PBC, PROT and LPC are below the limits cited. The European legislation or dairy processors have no specifications for thermophilic bacteria in milk. The farm milk samples also had a low level of contamination with BAC (non-detected to 2.00 $\log_{10}$ cfu ml^{-1}) and SRC (non-detected to 1.00 $\log_{10}$ cfu ml^{-1}). The TBC, PBC, PROT and LPC levels in the collection tankers samples were also below the limits cited. The TBC, PBC and PROT levels were higher in the WMS than in the collection tanker samples, which could be due to the silo or transference equipment (pipes, pumps, filters) cleaning practices. The TBC was above the limit specified in legislation for milk prior to processing (5.48 $\log_{10}$ cfu ml^{-1}; EC no 853/2004). The temperature applied during pasteurisation (75 °C, 25 s) was effective in significantly reducing the TBC, PBC and PROT levels, as observed in the SMS samples. The subsequent processing, where high temperatures were applied, also contributed to further reductions in those bacterial counts, as observed in the SMP samples (Table 1). The LPC and THERM levels were similar in the WMS and SMS samples, indicating that pasteurisation was not efficient in reducing those bacteria numbers, possibly due to the high temperatures applied, which are favourable for the growth of thermoduric and thermophilic bacteria; also, spores can survive high temperatures. The highest bacterial counts in the SMP samples were LPC and THERM; however, THERM counts were below the industrial limit applied in the USA for milk powder (4.00 $\log_{10}$ cfu g^{-1}). The composition of the milk transported by the tankers was similar

Table 1. Average (± SD) total bacterial count (TBC), psychrotrophic (PBC), proteolytic (PROT), thermoduric (LPC) and thermophilic (THERM) bacterial counts of milk samples from the farm bulk tanks, collection tankers, whole milk silo (WMS) and skim milk silo (SMS), and of the skim milk powder (SMP) samples.

Samples	Bacterial counts ($\log_{10}$ cfu ml^{-1})				
	TBC	PBC	PROT	LPC	THERM
Farm bulk tanks	3.78 ± 0.08	3.74 ± 0.09	3.54 ± 0.17	1.26 ± 0.11	0.90 ± 0.11
Collection tankers	3.90 ± 0.41	3.70 ± 0.55	3.64 ± 0.35	1.38 ± 0.44	1.43 ± 0.68
WMS	5.89 ± 0.02	6.00	5.45 ± 0.62	1.55 ± 0.17	2.00 ± 0.14
SMS	2.61 ± 0.20	2.00	2.00	1.69 ± 0.07	1.85 ± 0.10
SMP[1]	2.36 ± 0.09	0.99 ± 0.48	1.24 ± 0.53	2.45 ± 0.09	3.63 ± 0.12

[1] Results given in $\log_{10}$ cfu g^{-1}.

to the composition of the raw milk collected from the corresponding farms, and no differences were noticed in the WMS, as expected (Table 2). After cream separation, the fat content in the SMS samples decreased, while the protein and lactose contents remained the same (Table 2). The average SCC in the farm milk samples was $135 \pm 73 \times 10^3$ cells ml^{-1} (range: 36 to 342×10^3 cells ml^{-1}) and was below the European threshold limit (400×10^3 cells ml^{-1}). The average SCC in the tanker milk samples and WMS were similar: $139 \pm 42 \times 10^3$ cells ml^{-1} and $126 \pm 3 \times 10^3$ cells ml^{-1}, respectively. The SCC decreased in the SMS samples ($98 \pm 8 \times 10^3$ cells ml^{-1}), possibly due to the separation of somatic cells with the cream.

Table 2. Average (± SD) fat, protein and lactose contents of the milk samples from the farm bulk tanks, collection tankers, whole milk silo (WMS) and skim milk silo (SMS) and of the skim milk powder (SMP) samples.

Samples	Fat %	Protein %	Lactose %
Farm bulk tanks	3.76 ± 0.05	3.44 ± 0.02	4.89 ± 0.01
Collection tankers	3.76 ± 0.12	3.44 ± 0.06	4.90 ± 0.04
WMS	3.85 ± 0.01	3.42 ± 0.01	4.88 ± 0.03
SMS	0.08 ± 0.05	3.54 ± 0.01	5.08 ± 0.01
SMP (reconstituted)	0.09 ± 0.03	3.45 ± 0.05	4.88 ± 0.08

Conclusion

Milk of good microbiological and compositional quality was produced from grass-based systems, contributing to the production of good quality milk powder. The differences in bacterial counts between production stages are indications of the growth potential of the bacteria in the milk, or even an indication of possible contamination sources. Also, the reduction of bacterial counts is evidence of the effectiveness of pasteurisation. This study can aid industry in the development of new sanitation procedures, process controls or optimisation of processes parameters and practices to control bacterial numbers in order to ensure the consistent production of safe high-quality dairy products.

Acknowledgements

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Milk price volatility- does it affect the relative profit ranking of dairy herds in Ireland?

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Keywords: stocking rate, dairy farm profitability

Introduction

The abolition of EU milk quota affords an opportunity for dairy farmers to increase milk output, but it is also associated with a greater degree of farm-gate price volatility for globally traded milk products. For pasture-based systems in Ireland, access to land that can be utilised for grazing by the milking herd is now the principal limiting factor to herd expansion. Some farmlet and modelling studies, having controlled for pasture use efficiency differences, have reported quadratic effects of stocking rate on farm profit (MacDonald *et al*, 2011), and sensitivity to milk and feed prices (Ruelle *et al*, 2017), resulting in a moderate degree of re-ranking depending on scenarios tested. The current study examined the degree to which the relative profitability per hectare of dairy farms in Ireland changes to milk price fluctuations.

Materials and methods

Data for 849 dairy farms in 2016 were obtained from the Teagasc eProfit Monitor system, a benchmarking resource in which client farm data are recorded by Teagasc extension officers. Data included milk output and stocking rate, direct and overhead production costs. Using a multiple component pricing system, two annual base milk prices were imposed on each farm's production data, equivalent to €0.24 kg^{-1}(Low) and €0.34 kg^{-1}(High) of milk at standard composition. Profitability per ha farmed and per litre was calculated at both milk prices. Farms were ranked on relative profit at each milk price, and ranking scores compared using the REG procedure in SAS. Physical performance of the highest and lowest profit quintiles per ha farmed at each milk price were compared using the GLM procedure in SAS.

Results and discussion

There were strong associations between relative farm profit rankings at low and high prices, both per litre ($R^2 = 0.86$), and per ha farmed ($R^2 = 0.85$), demonstrating a low level of re-ranking due to milk price fluctuation. The most profitable quintile of farms at either milk price had higher whole farm stocking rate (2.47 vs 2.14 livestock units ha^{-1} at Low price; 2.49 vs 2.03 livestock units ha^{-1} at High price, $P < 0.05$). The most profitable farms tended to have lower purchased feed costs (€0.0123 kg^{-1} milk at Low price ($P < 0.01$); €0.0058 kg^{-1} milk at High price ($P = 0.06$). Milk solids kg produced per cow was higher ($P < 0.001$) for the highest profit quintiles at both base milk prices.

Conclusion

Dairy farms achieving higher milk solids output ha^1 through increased stocking rate while controlling purchased feed costs maintained a profit advantage across a range of milk prices. Variation between farms may be more appropriately described as differences in technical feed and grazing efficiency within a system, as opposed to differences between systems *per se*.

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Grass-to-maize silages ratio affects dairy milk yield and milk fatty acids composition

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Abstract

The objective of this trial was to evaluate the effects of different proportions of grass silage and maize silage on dairy cow´s productivity, milk composition and milk fatty acids (FA) profile. Within a 4 × 4 Latin square design, four diets were randomly assigned to 24 Holstein dairy cows divided in four groups during four periods of three weeks each. Rations were composed by 350 g kg^{-1} dry matter (DM) of concentrates of variable crude protein content, 50 g kg^{-1} of grass hay and 600 g kg^{-1} DM of grass silage (GS) and/or maize silage (MS) which varied, respectively in proportions 600:0, 400:200, 200:400 and 0:600 (treatments MS0, MS200, MS400 and MS600, respectively). The substitution of GS by MS increased milk yield, milk protein, milk fat and milk protein content with an optimum level of maize silage inclusion found at MS400. Increasing the level of MS in the diet raised the saturated FA (SFA), palmitic content and the omega-6 /omega-3 FA ratio, but reduced the proportion of monounsaturated oleic and polyunsaturated alpha-linolenic acids, showing evidence of a healthier milk FA profile in all-grass silage diets.

Keywords: dairy cow, grass silage, maize silage, milk, fatty acids

Introduction

Grass silage and maize silage are the main conserved forages consumed in Galician dairy farms. In the last decades, maize crop for silage has developed in parallel with the intensification of dairy farming in Galicia. Flores *et al.* (2017) reported that about 75% of dairy milk production in Galicia comes from farms that use diets based on maize silage as the main forage ingredient, being complemented in most cases with grass silage in variable proportions. While smaller dairy farms tend to be more dependent on grass silage for cows' feeding, the importance of maize silage increases with farm size. Research shows that, in general, higher levels of inclusion of maize silage in dairy cows' diets is associated with higher animal performance in terms of milk yield (Khan *et al.*, 2015). Nowadays, the public concern about the relationships between diet and human health which has led to an increasing interest of consumers about 'healthy' food products, amongst which the dairy milk is included. Bioactive FA such as alpha-linolenic (C18:3n3), vaccenic (*t*11 C18:1) and rumenic (*c*9, *t*11 CLA) are typically present in low percentages in milk (> 50 g kg^{-1} total FA) but exert a significant biological impact in human health (Parodi, 1997). Milk fatty acid composition can be significantly altered through the diet of the dairy cows (Givens and Shingfield, 2006), offering the opportunity to respond to market forces and human health recommendations. The objective of this trial was to evaluate the effects of the progressive substitution of grass silage (GS) by maize silage (MS) in dairy cows' diets on milk yield, milk composition and milk FA profile.

Materials and methods

The experiment took place in autumn 2016 at the CIAM research station farm (Galicia, NW Spain), using 24 Holstein dairy cows with average milk yield of 36.1 ± 8.8 kg day^{-1}, 62 ± 16 days in milk and 628 ± 65 kg liveweight. Cows were distributed in four homogeneous groups during four periods of three weeks each, following a 4 × 4 Latin square design. Animals were fed one of four isonitrogenous experimental diets, composed of 350 g kg^{-1} DM of concentrates of variable crude protein (CP) content, 50 g kg^{-1} of grass hay and 600 g kg^{-1} DM of grass and/or maize silages. The relative proportions of GS to MS (in g kg^{-1} of total diet DM) varied as follows: 600 to 0, 400 to 200, 200 to 400 and 0 to 600 (treatments MS0, MS200, MS400 and MS600, respectively). Daily voluntary intake of individual cows was recorded electronically. Milk yield per cow was measured daily and individual milk samples were taken during three consecutive days in the last week of each period. Samples were immediately stored at 4 °C and transported to the official regional interprofessional milk laboratory (LIGAL) where they were subjected to routine FTMIR analysis (milk composition) or immediately frozen (-20 °C) until posterior FA analysis. A composite sample of the two milkings per cow of every sampling day was analysed by gas chromatography (GC-FID) following the LIGAL standard procedures ISO 14156/IDF 172 and ISO 15885/IDF 184.

Results and discussion

Silage characteristics (not shown in tables) indicated a low-medium quality of GS (DM 367 g kg^{-1}, CP 100 g kg^{-1} DM, metabolisable energy ME 9.2 MJ kg^{-1} DM) and a good quality of MS (DM 338 g kg^{-1}, CP 80 g kg^{-1} DM, starch 292 g kg^{-1}, ME 11.0 MJ kg^{-1} DM), being representative of usual Galician silages of both types. Average total mixed rations CP content varied little amongst treatments, from 153 to 158 g kg^{-1} DM. Table 1 shows a positive quadratic effect of the inclusion of MS in GS on milk yield was observed, reaching a maximum value of 36.2 kg d^{-1} in MS400, significantly higher compared with the rest of the diets. Milk protein yield was also significantly higher in MS400 and MS600 (1.13 and 1.16 kg d^{-1}) with respect of the lowest levels of maize silage inclusion (0.97 and 0.92 kg d^{-1} for MS200 and MS0, respectively). Milk protein content linearly increased from 31.4 g kg^{-1} in MS0 to 33.5 g kg^{-1} in MS600.

Table 1. Effect of substitution of grass silage by maize silage in dairy cows' rations on dry matter intake, milk yield, milk composition and milk fatty acid composition.[1]

	Treatments				P
	MS0	MS200	MS400	MS600	
n	72	72	72	72	
DMI (kg cow^{-1})	21.9^{c}	23.0^{b}	23.9^{a}	24.1^{a}	***
Milk yield † (kg cow^{-1} d^{-1})	31.3^{d}	33.2^{c}	36.1^{a}	34.6^{b}	***
Milk composition kg (g kg^{-1})					
Fat	40.3^{b}	42.1^{a}	38.4^{c}	33.9^{d}	***
Protein	31.4^{b}	31.9^{b}	33.2^{a}	33.5^{a}	***
Lactose	47.5	47.8	48.1	48.0	ns
Main FA groups (g kg^{-1} total FA)					
Saturated (SFA)	673.7^{b}	709.4^{a}	728.4^{a}	713.2^{a}	***
Monounsaturated (MUFA)	240.6^{a}	246.7^{a}	225.9^{b}	239.4^{ab}	*
Polyunsaturated (PUFA)	35.2^{a}	35.9^{bc}	37.4^{b}	40.0^{a}	***
Individual FA (g kg^{-1} total FA)					
Linoleic	18.4^{b}	19.3^{b}	20.9^{a}	21.8^{a}	***
*c*9, *t*11 CLA	6.2^{b}	5.2^{c}	5.6^{c}	7.2^{a}	***
*t*10 C18:1	3.4^{bc}	2.6^{c}	4.4^{b}	9.1^{a}	***
*t*11 C18:1	12.7^{a}	11.2^{bc}	10.8^{c}	11.9^{ab}	***
Alpha-linolenic	5.2^{a}	4.5^{b}	3.5^{c}	3.0^{d}	***
Ratios of fatty acids					
*t*11/*t*10 C18:1	5.29^{a}	4.41^{b}	3.02^{c}	2.25^{d}	***
Omega-6/Omega-3	2.73^{d}	3.20^{c}	3.77^{b}	3.90^{a}	***

[1] n: number of observations; †Corrected 3.5% fat and 3.2% protein; DMI: Dry matter intake; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; figures affected by different letters in the same row are significantly different.

The highest milk fat content was found in M200 and a lowest in M600 (42.1 and 33.9 g kg^{-1}, respectively) following a quadratic response to the increment of MS in ration, and milk fat yield was maximised in MS400 (1.32 g kg^{-1}) being minimal with the lowest and highest maize silage levels of inclusion in diet (1.19 and 1.18 kg d^{-1}, M0 and M600 respectively).

As expected, the substitution of GS by MS altered milk FA profile. Treatments M0 and M200 showed the lowest contents of SFA (673 and 709 g kg^{-1}), palmitic acid (317 and 316 g kg^{-1}) and omega-6 / omega-3 ratio (2.7 and 3.2) compared with the rest of the diets. The increment of the proportion of maize silage in the rations decreased the milk content of the beneficial oleic acid and alpha-linolenic acid (from 192 to 164 g kg^{-1} and from 5.2 to 3.0 g kg^{-1}, respectively, for M0 and M600) whilst the linear increment in total polyunsaturated FA from M0 (35.2 g kg^{-1}) to M600 (40.0 g kg^{-1}) was mainly due to a higher presence of linoleic acid that, although an essential FA, is considered to be in excess in the diet of developed countries.

These results are in general agreement with other authors studies (e.g. Kliem *et al*., 2008) that found that the substitution of GS with MS in dairy cows' diets had a positive effect in milk yield and milk protein yield but not the milk FA profile. It is necessary to take into account that, as stated by Khan *et al*. (2015), these responses can be modified by the relative quality of grass and maize silages.

Conclusion

The partial substitution of grass silage with maize silage in high-forage total mixed diets for dairy cows improved animal performance and altered the FA milk composition. All-grass silage based diets seem to have a better FA profile from a human diet perspective.

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Suburban context modifies the way dairy farmers reason the role of grasslands in forage management

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Abstract

Since the nineties, there has been a renewed interest in grasslands for their multifunctionality in the agricultural sector and in society, especially in suburban areas. The objective of this study was to examine whether this new interest has impacted on the way dairy farmers think about forage management. A qualitative survey was carried out on 15 dairy farmers in a suburban area where grassland is maintained and the ensuing farmers' responses analysed. Five ways of thinking were identified: (1) grazing: grasslands are thought to be central to the forage system with milk production aligned to pasture potential; (2) careful grazing: grasslands are considered important but requiring of maize silage to secure milk production; (3) sustainable: grasslands are considered to increase sustainability of forage systems relying heavily on maize; (4) production security: maize is considered the only crop capable of securing high levels of milk production; (5) traditional: grasslands belong to an inherited forage system without a long-term strategy. The well-documented opposition between grassland and maize is attenuated in groups two and three, which are based on complementary use of both to achieve intensive and sustainable milk production. This change is linked to the suburban context, where farmers are continually questioned about the sustainability of intensive farming by professional and social networks.

Keywords: grasslands, suburban, farmer's conceptions, dairy cattle

Introduction

There is currently a renewed interest in grasslands. Grasslands are promoted by agricultural policies; they provide a possible solution to overdependence on external forage for dairy herds. They are identified as important for the environment and biodiversity and are also valued in several Protected Designation of Origin (PDO) products and other food quality labels. In spite of public policies and technical tools promoting grassland use, grassland areas are still decreasing, mainly in lowland areas where cattle production is dominant (-2% between 2000 and 2010) in France, (Agreste, 2010). Nevertheless, a recent study based on the last two French agricultural census datasets (2000 and 2010) highlighted that, in some areas, grassland was maintained over the period of general decrease of this land cover type (Couvreur *et al.,* 2016). This work was focused on one of these areas, located in suburban Rennes (Brittany, France). Various technical pathways of grassland maintenance at farm scale (Petit *et al.,* 2016) were observed which were not linked to either structural determining factors of farms or to dairy sector dynamics (Petit *et al.,* 2017). For this purpose, the identification of how farmers consider grasslands and forage management and their relation to the suburban context was sought. The hypothesis was that grassland maintenance at farm scale is linked to various interpretations of the highly demanded multifunctionality of grasslands in a suburban context (Hopkins and Holz, 2006).

Materials and methods

In 2016, we studied 15 dairy and/or beef cattle farms, selected to be representative of the diversity of farming systems in the suburban area of Rennes (north west France) in terms of production and farm size (Petit *et al.*, 2016). Data was collected via one to one qualitative surveys with farmers. The first two interviews dealt with changes over time of: (1) the structure of the farming system (Utilized Agricultural

Area, work force, production facilities), the different crop and animal productions (production volume, number of animals, crop rotations) and (2) grassland management (types of grassland, type of forage, grass forage quality and quantity, grazing management and crop rotations including grassland). Those two interviews were partially transcribed, focusing on the reasons given for farming practices. A third interview dealt with the social and professional network of the farmers to test for possible urban influence on practices. This interview was fully transcribed. Firstly, the following key information that appeared in farmers' responses was extracted: (1) the aim of grassland use, (2) grassland management methods, (3) use of maize, (4) the role of animals and their place in the system, (5) the economic strategy and (6) the work force. We found several types of response corresponding to different sociological representations. Once the different ways of thinking about forage management and grassland use were identified, the connection between these and a farmer's socio-professional network, in particular, his (1) career, (2) professional sociability and (3) social relations were analysed.

Results and discussion

We highlighted five ways of thinking about forage management (Figure 1): (1) grazing (n = 4): grasslands are thought to be central for the forage system with milk production aligned to pasture potential; (2) careful grazing (n = 2): grasslands are considered important but requiring of maize silage to secure milk production; (3) sustainable (n = 4): grasslands are considered to increase sustainability of forage systems relying heavily on maize; (4) production security (n = 3): maize is considered the only crop capable of securing high levels of milk production; (5) traditional (n = 2): grasslands belong to an inherited forage system without a long-term strategy. The different ways of thinking show that grassland can be integrated either as a central element of the forage system or as a component among others. It seems there is a gradient of maize and grassland use which suggests that the well-documented opposition between those forages is fading, being replaced by complementary use of both to achieve intensive and sustainable milk production.

From analysis of farmers' responses, it appears that age and background poorly explain the ways they think about forage management. Professional networks (advice and professional groups) are strongly linked to the different ways of thinking about forage management at farm scale and confirm the influence of social networks in the adoption of agricultural practices (Ramirez, 2013). *Grazing* and *Careful grazing*

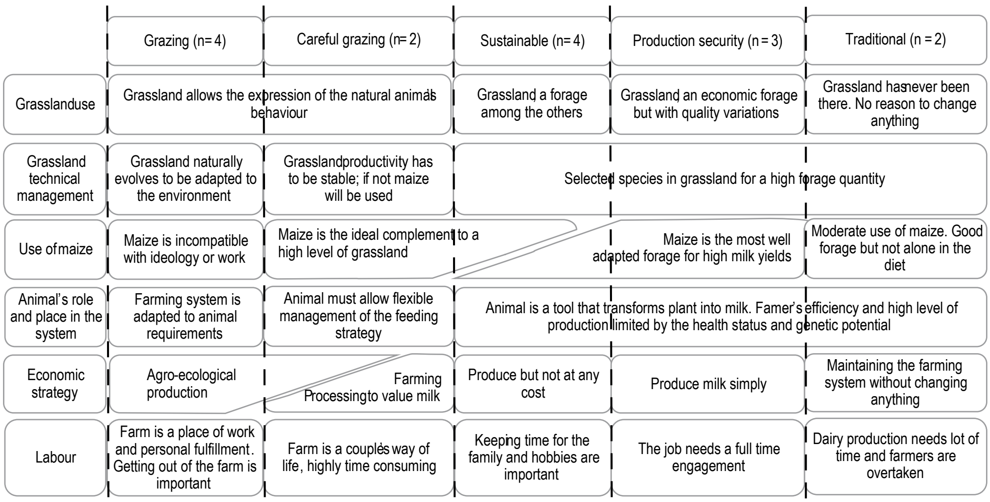

Figure 1. Construction of the different ways of thinking about forage management.

farmers participated in groups promoting farm forage autonomy and keeping external feed sources to a minimum through cultivation of grassland. They changed professional networks at the same time as they modified their use of grassland. *Sustainale* farmers participated in dominant professional groups. Their changes to grassland use did not come through these groups but rather through exchange with neighbours and adaptation of techniques observed in farms using high levels of grassland. *Production security* and *Traditional* farmers were less engaged in professional groups and preferred individual advice.

Urban proximity, through neighbourhood relationships, sales relations or societal demands for more sustainable forms of agriculture, did not affect farmers in the same way. It consolidated the choices made by farmers using high levels of grassland (*Grazing* and *Careful grazing*) and questioned all the other groups of farmers, pushing them to change their practices (weed killer treatment on crops near residential areas…). The disappearing opposition between grassland and maize seems to be linked to the suburban context, in which farmers are continually questioned about the sustainability of intensive farming, by professional and social networks. This shows how society can play, directly or indirectly, a role in changing agricultural practices (Maréchal and Spanu, 2010).

Conclusion

Grassland is a multifunctional land use that is discussed, directly or indirectly, by farmers and society. Used for animal feeding, grasslands contribute to the evolution of dairy systems towards agroecological practices promoted by society. An issue for the future is to better understand the interactions between professional and social networks that could make it possible to develop advice and support for grassland use in farms, as part of wider strategies at local or regional scales.

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Dairy cows with higher genetic merit for maintenance have a lower live-weight

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Keywords: dairy cow, genetic merit index, fertility

Introduction

Compact seasonal calving and breeding protocols ensure that the maximum numbers of cows are in peak lactation to coincide with peak pasture growth (Roche *et al.,* 2017). In temperate grazing systems this occurs in late spring and early summer (Roche *et al.,* 2009). Reproductive performance is of great importance in seasonal calving herds. Genetic merit for cow live-weight and fertility are negatively associated (Berry *et al.,* 2003). The total genetic merit index used in Irish dairy herds, the Economic Breeding Index (EBI) comprises traits, arranged in sub-indexes which impact on profitability. The maintenance sub-index is calculated from the carcass weight of slaughtered cull cows multiplied by an economic value of -€1.65. This analysis investigates the association between the maintenance sub-index and actual cow live-weight.

Materials and methods

The live-weight records of 22,705 cows sold singly in livestock marts in the year 2016 were obtained. Data were edited to remove cows weighed < 10 days or > 200 days post-calving and cows of beef-breed origin. Parities ≥ 4 were grouped. A mixed model adjusted for cow-herd, parity, days since last calving, and the calendar month of the year of weighing was used to quantify the association between predicted and actual live-weight.

Results and discussion

The mean live-weight of cows within €10 brackets of maintenance sub-index is presented in Figure 1. Each €10 increase in cow maintenance sub-index was associated with 41.6 kg lighter cow live-weight; similarly each unit increase in cull-cow weight genetic merit was associated with 3.4 kg increase in live-weight. Assuming a kill out of 45%, one would expect the latter value to be 1.5 kg.

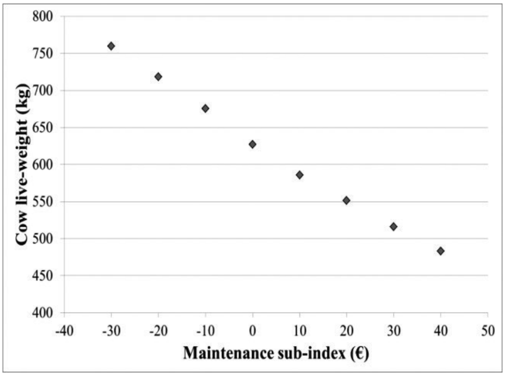

Figure 1. Mean cow live-weight across different maintenance sub-index values.

Conclusions

These results show that higher values of maintenance genetic merit translate to lower cow live-weight on-farm.

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How four typical Swedish production systems for lambs affect sensory attributes of the meat

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Abstract

The aim of this study was to evaluate the effect of the four most typical production systems for Swedish lamb on sensory attributes of meat, including appearance, texture, taste and flavour using an analytical panel. The experiment included four production treatments for weaned intact male lambs: (1) indoor fed with grass and clover silage *ad libitum* and 0.8 kg concentrate daily per lamb; (2) grazing on cultivated pasture with; or (3) without 0.3 kg concentrate supplementation daily per lamb; and (4) grazing on semi natural pasture; eight lambs per production treatment were used. Feed rations, pasture height and live weight of the lambs were recorded. At slaughter, live weight, carcass conformation, fatness, pH and temperature decline in muscle during 24 hours after slaughter were registered. Sensory and technological meat quality parameters were tested in cooked samples of *M. longissimus dorsi*. Meat colour was not affected by treatment. Most sensor attributes were unaffected by production system but for 'hay odour' and 'resistance to cutting', differences between the systems were manifested.

Keywords: live weight gain, pH-value, temperature, sensory attributes, texture, colour

Introduction

It is well known that meat quality is a complex subject that includes a multitude of parameters. These parameters are, in turn, affected by many factors e.g. the production system with different feeding strategies, breeds and sexes (Toldrá, 2017). In 2016, the Swedish sheep and lamb meat production accounted for only 28% of the total Swedish consumption (Jordbruksverket, 2017). To satisfy the consumers' demand of lamb meat, with a consumption of 1.8 kg lamb meat per person annually, the import of sheep and lamb meat increased substantially both in 2015 and 2016 (Jordbruksverket, 2017). An increasing demand of high quality lamb meat produced in Sweden results in a need to know how lamb should be reared under Swedish conditions, with the goal to obtain a high and consistent eating quality. Consumers usually determine meat quality by its eating quality, where tenderness, juiciness and flavour are the most important elements (McIlveen and Buchanan, 2001). The eating quality of today's Swedish lamb meat varies, which might be due to, for example, the use of different production systems, different breeds, slaughter ages and weights. It has been shown that different diets could affect the meat quality of lamb. Different feeding strategies could be grazing contra grain feeding, which could affect the flavour of the meat, for example (Watkins *et al.*, 2013). The aim of this study was to evaluate the impact of different production models on meat quality attributes.

Materials and methods

In total, 32 crossbred intact ram lambs (Dorset × Fine Wool; 75:25) were included in the study. Groups of eight animals were assigned to one of four production treatments for weaned intact male lambs; Group 1 on indoor feeding, Groups 2 and 3 on cultivated pasture with or without supplemented concentrate, respectively, and Group 4 on semi-natural pasture. All animals in the study had access to water, salt and minerals *ad libitum*. Group 1 was offered a total mixed ration consisting of grass and clover silage *ad libitum* and a constant amount of 0.8 kg concentrate per lamb and day. Groups 2 and 3 grazed two different enclosed pastures of total 1.0 ha, divided in three paddocks each. In addition to grass, Group 2 was offered 0.3 kg of concentrate per lamb and day, offered in feed troughs at pasture once a day. Group 4 was grazed in a semi natural pasture. The chemical composition of silage and pastures regarding metabolisable energy (MJ kg^{-1} DM) and digestible protein (g kg^{-1} DM) were 11.4 / 126.3 (Group 1), 11.5 / 140.0 (Group 2), 10.4 / 126.5 (Group 3) and 11.6 / 179.8 (Group 4), respectively. All lambs were weighed each week and body (hull) assessment was used to determine when each individual lamb was mature enough to go to slaughter. At slaughter, parameters such as slaughter weight, carcass conformation, fatness, pH and temperature decline over 24 hours were recorded. The pH and temperature meters were inserted in the *M. adductor* in all carcasses. After six days of ageing, *M. longissimus dorsi* were sampled, immediately frozen and stored at -20 °C until analysis. Samples of *M. longissimus dorsi* were thawed and cooked using the *sous vide* method to an internal temperature of 65.5 ± 1.2 °C. The samples were chilled overnight and sliced in 5 mm slices. Samples were held at 70 °C for 10 minutes whereupon served. Sensory analysis was performed by a trained panel consisting of six assessors. The sensory data was analysed by two-way ANOVA (Proc Mixed SAS, version 9.4), with production system as fixed and assessors as random factors. Differences were considered significant when $P < 0.05$.

Results and discussion

Live weight gain and carcass quality characteristics, as well as meat colour, are presented in Table 1. The results from the meat colour measurements (L *, a * or b *) showed no differences between treatments. This result indicates that neither LWG, nor age at slaughter affected colour, nor did the extra supplemented concentrate nor the different pasture types. Regarding the sensory attribute 'resistance to cutting' (Table 2), Group 3 was scored lower compared to Groups 2 and 4. It is important to acknowledge that similar differences were not found for growth intensity in that case. There was also a strong tendency ($P = 0.05$) for Group 4 being scored higher than the other groups for the attribute 'hay odour'. The indication that the meat from lambs grazing semi natural pasture may be related to the lower growth rate and a higher age at slaughter for this group would be interesting to investigate further. The results in Table 1 indicate that there were no differences for the sensory attributes with differences in growth rate and final pH after 24 h. According to these results, individual differences between animals could be speculated about rather than differences of production systems. Growth rate and pH value of the meat are considered as tools to predict sensory attributes, such as tenderness and in this study there were no clear relationships.

Table 1. Carcass and meat quality from lambs reared in the different production models.

Parameters	Group 1[1]	Group 2	Group 3	Group 4	SEM[2]	Significance
Weight at slaughter (kg)	51.8	50.3	49.2	50.9	0.71	NS
Growth rate (g day^{-1})	406^{a}	303^{b}	256^{c}	224^{d}	0.01	< 0.0001
Carcass weight (kg)	21.6^{a}	21.3^{a}	20.9^{a}	18.8^{b}	0.47	0.0027
Conformation score[e]	9.4	9.1	9.4	9.0	0.34	NS
Fatness score[e]	7.3^{ab}	7.9^{a}	7.8^{a}	6.8^{b}	0.26	0.02
pH after 24 h	5.92^{a}	5.88^{a}	5.72^{ab}	5.56^{b}	0.10	0.059
Temperature after 24 h (°C)	2.6^{c}	2.9^{bc}	3.7^{a}	3.2^{b}	0.12	< 0.0001
Colour Lightness (L *)	37.1	37.2	36.5	35.7	0.67	NS
Colour Redness (a *)	16.9	16.5	16.6	16.4	0.27	NS
Colour Yellowness (b *)	7.2	7.0	6.8	7.1	0.33	NS

[1] Group 1 on indoor feeding, group 2 on cultivated pasture with 0.3 kg supplemented concentrate per lamb daily, group 3 on only cultivated pasture and group 4 on only semi natural pasture.

[2] SEM = standard error of the mean.

[a-b]Mean values with different superscripts in the same row differ significantly ($P < 0.05$). NS: non-significant ($P > 0.05$).

[e]According to the EUROP-system ranging from 1 (very bad conformation / very low fat) to 15 (very good conformation / very high fat).

Table 2. Sensory attributes from lambs reared in the different production models.

Parameters	Group 1[1]	Group 2	Group 3	Group 4	SEM[2]	Significance
Pinkness	46[3]	47	45	46	2.34	NS
Fibre structure	37	35	35	33	1.57	NS
Total lamb meat odour	48	48	49	49	1.07	NS
Acidic odour	32	30	31	33	0.97	NS
Hay odour	30^{a}	29^{a}	29^{a}	32^{b}	1.07	0.051
Resistance to cutting	37^{ab}	43^{a}	33^{b}	39^{a}	1.91	0.017
Softness	55	50	55	54	1.90	NS
Tenderness	60	52	65	61	3.47	NS
Crumbliness	45	41	49	50	3.31	NS
Total lamb meat flavour	54	53	54	56	1.16	NS
Metal flavour	38	42	41	43	1.57	NS
Leafy flavour	31	33	33	35	2.43	NS
Oiliness	34	35	34	36	1.16	NS

[1] Group 1 on indoor feeding, group 2 on cultivated pasture with 0.3 kg supplemented concentrate per lamb daily, group 3 on only cultivated pasture and group 4 on only semi natural pasture.

[2] SEM = standard error of the mean.

[3] Scores are between 0-100.

[a-b] Mean values with different superscripts in the same row differ significantly ($P < 0.05$). NS: non-significant ($P > 0.05$).

Conclusion

The results from this study indicate that intact ram lambs reared to four different production treatments (indoor, cultivated pasture with or without supplemented concentrate or semi natural pasture), covering the Swedish lamb production, did not seem to affect technological meat quality in terms of final pH and temperature of lamb carcasses. Meat colour was not affected by treatment. Sensory parameters that were affected by production system were 'hay odour' and 'resistance to cutting'. With that in mind, it seems that the different production systems did not have an overall effect on eating quality such as tenderness and flavour that are the most important from a consumer perspective. From this study it was also found that in general the variation between animals was higher than between different rearing systems.

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The impact on sheep performance of incorporating daffodil production within grazed upland permanent pasture

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Keywords: grazing, lambs, live-weight gain, alkaloid, Alzheimer's

Introduction

Daffodils (*Narcissus pseudonarcissus*) produce an alkaloid, galanthamine, which can be used as a treatment for Alzheimer's disease. Within Europe, daffodil-derived galanthamine is the only economically feasible plant source for cultivation. Feasibility studies have confirmed that integrating daffodils into existing marginal pasture in upland areas could provide an economical sustainable source for galanthamine whilst maintaining traditional farming practices in upland areas. The alkaloid produce by the daffodils is toxic to animals if consumed. Research was, therefore, needed to assess if grazing livestock will naturally avoid consuming the daffodils and if there are any underlying secondary health risks associated with consumption. This study directly compared the liveweight gain of lambs grazing pasture with and without daffodils.

Materials and methods

Sheep performance was assessed on replicate 0.9 ha plots in which daffodils have been integrated into existing upland permanent pasture in lines 0.8 m apart. The study consists of three experimental treatments: 1) Permanent pasture with fertiliser applied at a rate of 50 kg ha^{-1} N, 25 kg ha^{-1} P & 25 kg ha^{-1} K (Control); 2) Permanent pasture under-sown with daffodils, with fertiliser applied at a rate of 50 kg ha^{-1} N, 25 kg ha^{-1} P & 25 kg ha^{-1} K (Daffs 50N); 3) Permanent pasture under-sown with daffodils, with fertiliser applied at a rate of 25 kg ha^{-1} N, 12.5 kg ha^{-1} P & 12.5 kg ha^{-1} K (Daffs 25N; testing fertiliser impacts on galanthamine). Once the daffodils were harvested, Beulah Speckle Faced ewes and lambs grazed the pastures, from turn out in early May to weaning in late July, at a rate of nine ewes ha^{-1} and 14 lambs ha^{-1}. Sward surface height was consistently greater than 6.5 cm. In order to assess livestock performance, all the animals were weighed every two weeks during the grazing period. Body condition scores of the ewes were recorded at the beginning, weaning and at the end of the grazing period.

Results and discussion

Sheep were not observed eating daffodils. Results obtained in the first year of a three year study indicate no effect on the growth rate of lambs between plots incorporating daffodils and control plots (mean values = 184 g d^{-1} (Control), 210 g d^{-1} (Daffs 50N), 206 g d^{-1} (Daffs 25N), s.e.d = 13.7 g d^{-1}, ns). The results indicate that planting daffodils under grass in upland areas need not comprise subsequent sheep performance. This supports the development of dual-cropping systems simultaneously producing high value chemicals and livestock products from marginal areas.

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Milk yield and milk composition characteristics of grazing and all-silage dairy systems

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Abstract

With the objective of evaluating the variability in dairy cows' milk yield, milk composition and milk fatty acids (FA) profile when offering diets of varying degrees of intensification, 24 Holstein-Friesian dairy cows were randomly assigned to four feeding groups of contrasting diet composition for 12 weeks after peak milk yield. Two groups had access to a perennial ryegrass sward, either continuously during 24 h (T1) or between morning and evening milkings (T2), and two groups (T3 and T4) were kept indoors throughout the experiment, having *ad libitum* access to total mixed rations (TMR), which differed in the composition of the silages (grass and maize or maize alone) and in concentrate proportion. T1 and T2 were supplemented, with 2 kg cow^{-1} d^{-1} of concentrate dry matter (DM) and with 10 kg DM cow^{-1} d^{-1} of a TMR based on maize silage and concentrates, respectively. Milk yield increased from 31.4 kg d^{-1} in T1 to 37.8 kg d^{-1} in T4 with moderate changes in milk components. Compared with all-silage, high-concentrate diets, milk from grazing-based systems showed a less-saturated FA profile, a higher content in the beneficial FA *c9t11*-CLA, *t11*-C18:1 and C18:3n3 and a lower omega-6 to omega-3 ratio.

Keywords: dairy cow, grazing, silages, milk, fatty acids

Introduction

Galicia is among the ten regions of the EU with the highest level of cow milk production (Eurostat, 2013). Several production models are used on Galician dairy farms, but the predominant one in large farms is usually based on the intensive use of concentrates and maize/grass silage. Only in smaller holdings and in some specialised farms, feed management is based on grazing during the periods of active grass growth in spring to mid-summer and in autumn. There is an increased consumer interest in this type of dairy production, based on the positive perception of being a more 'natural' way of producing milk with better standards of animal welfare and an improved milk quality from the perspective of its inclusion in the so-called 'healthy diet'. Since it is well established that feeding cows with fresh grass increases the content of beneficial milk fatty acids (FA) (e.g. Dewhurst *et al.*, 2006) and improves its 'healthy value', it was considered of interest to perform an experiment to evaluate the effect of imposing contrasting diets of varying degrees of intensification based on fresh grass and/or grass and maize silages on cows' performance and milk composition. The objective of this paper was to understand the relationships between the different diets offered in the Galician dairy farms and the follow-on effect on milk characteristics, components and milk FA profile.

Materials and methods

The experiment was performed from 10 April to 2 July 2017 at the Centro de Investigacións Agrarias de Mabegondo (CIAM) research station farm (Galicia, NW Spain, 43° 15′ N, 8° 18′ W, 100 m above the sea level). Twenty four Holstein dairy cows with a milk yield of 40.1 ± 6.8 kg d^{-1}, 81.2 ± 17.3 days in milk and a live weight of 602.6 ± 71.6 kg were randomly assigned, following a completely randomised design, to four feeding groups (six cows per group, one primiparous animal) for 12 weeks, with a preliminary adaptation period of two weeks. In two treatments cows were allowed to graze rotationally a perennial ryegrass sward (T1.-grazing 24 h d^{-1} plus 2 kg cow^{-1} d^{-1} of concentrate DM; T2.- grazing during the day between milkings plus 10 kg DM cow^{-1} d^{-1} of a TMR offered in the barn during the night) and in the other two treatments the cows remained confined throughout the experiment with *ad libitum* access to a TMR based on grass and maize silage (T3) or based on maize silage (T4). Concentrate level increased across T1 to T4 treatments and the approximate proportion of forage:concentrate DM was 90:10% (T1), 80:20% (T2), 60:40% (T3) and 50:50% (T4). The relative proportions of TMR ingredients for the T2, T3 and T4 treatments were maize silage: 495, 282 and 385 g kg^{-1}; grass silage: 0, 282 and 0 g kg^{-1}, grass hay: 99, 64 and 131 g kg^{-1} and concentrate: (240 g kg^{-1} of crude protein) 406, 372 and 485 g kg^{-1}. Daily voluntary intake of TMR consumed in the barn by T2, T3 and T4 cows was recorded electronically. Individual milk yield was measured daily and individual milk samples were taken once a week. Samples were immediately stored at 4 °C and transported to the official regional interprofessional milk laboratory (Laboratorio Interprofesional Galego de Análise do Leite, LIGAL) where they were subjected to routine FTMIR analysis (milk composition) using a MilkoScan™ FT6000 (Foss Electric A/S, Hillerød, Denmark) or immediately frozen (-20 °C) until posterior FA analysis. The commercial concentrate, 24% crude protein (CP), was the same for all treatments. A composite sample of the two milkings per cow at every sampling day was analysed by FID gas chromatography following the LIGAL standard procedure.

Results and discussion

Average values of voluntary DM intake of cows of the TMR offered indoors were 9.9, 23.2 and 23.6 kg DM cow^{-1} d^{-1}. Body condition score of the cows between the 1st and the 12th week of the experiment was -0.29, 0.0, +0.16 and +0.39 for T1, T2, T3 and T4, respectively. Daily milk yield per cow was significantly affected by treatment (Table 1), being significantly higher in T4 (38.5 kg d^{-1}) compared to the other treatments, followed by T3 and T2 with no significant differences between them (35.3 and 34.7 kg d^{-1}) and T1 (30.6 kg d^{-1}). Milk fat value observed in T1 was 32.8 g kg^{-1}, significantly lower than the rest of treatments, which were in a range of 35.0-35.6 g kg^{-1} and were not different from each other. Milk protein content increased from average values of 30.2-30.7 g kg^{-1} in T1 to T3 treatments, with no significant difference, up to 32.7 g kg^{-1} in T4. Milk lactose content followed a similar trend to that of milk protein. Diet dramatically affected milk FA profile. Milk saturated fatty acids (SFA) content from grazing cows (T1: 632 g kg^{-1}, T2: 664 g kg^{-1}) was significantly lower compared with indoor, silage-fed cows (T3: 721 g kg^{-1}, T4: 720 g kg^{-1}). Similarly, milk from grazing cows, and within them, particularly milk from the unrestricted grazing access group T1 showed significantly higher content values of total monounsaturated and polyunsaturated FA, vaccenic acid (*t11*-C18:1), conjugated linoleic acid (*c9t11*-CLA) and alpha-linolenic acid (C18:3n3), compared with the all-silage groups T3 and T4. Inversely, the ratio of total omega-6 to total omega-3 acids was lowest for T1 (1.31), followed by T2 (2.02), T3 (3.16) and T4 (4.62), all significantly different amongst them. The results agree globally with the observations of various researchers (e.g. Elgersma, 2015) indicating that milk from grazing-based systems has a FA profile, compared with more intensive diets based in starchy feeds, more appropriate for a healthy, human diet.

Conclusion

The results of this work show clearly that, from the perspective of the actual state of knowledge about dairy milk composition and human health, milk of grazing cows shows advantages in terms of an FA profile that makes it more suitable to be included in human diets.

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Table 1. Milk composition and milk fatty acids profile of the imposed treatments.[1]

	Treatments				P
	T1	T2	T3	T4	
n	72	72	72	72	
Milk yield (kg cow^{-1} d^{-1})†	30.6 ^{c}	34.7 ^{b}	35.3^{b}	38.5 ^{a}	<0.0001
Milk composition (g kg^{-1})					
Fat	32.8 ^{b}	35.0 ^{a}	35.0 ^{a}	35.6 ^{a}	<0.0001
Protein	30.7 ^{b}	30.2 ^{b}	30.3 ^{b}	32.7 ^{a}	<0.0001
Lactose	46.3 ^{c}	47.4 ^{b}	47.2 ^{b}	48.0 ^{a}	<0.0001
Main FA groups (g kg^{-1} total FA)					
Saturated (SFA)	632.3 ^{c}	664.4 ^{b}	721.2 ^{a}	720.3 ^{a}	<0.0001
Monounsaturated (MUFA)	306.9 ^{a}	282.1 ^{b}	234.3 ^{c}	231.2 ^{c}	<0.0001
Polyunsaturated (PUFA)	49.1^{a}	43.6 ^{b}	36.6 ^{c}	40.7 ^{b}	<0.0001
Omega-6 total FA	16.2 ^{d}	19.6 ^{c}	23.4 ^{b}	26.8 ^{a}	<0.0001
Omega-3 total FA	12.5 ^{a}	10.0 ^{a}	7.4 ^{c}	5.9 ^{d}	<0.0001
Individual FA (g kg^{-1} total FA)					
C16:0	244.9 ^{d}	270.0 ^{c}	322.6 ^{b}	340.4 ^{a}	<0.0001
Linoleic (C18:2cn6)	13.2 ^{d}	16.9 ^{c}	20.6 ^{b}	21.4 ^{a}	<0.0001
*t*10 C18:1	2.6 ^{c}	4.5 ^{b}	3.2 ^{c}	5.9 ^{a}	<0.0001
Vaccenic (*t11*- C18:1)	49.7 ^{a}	33.5 ^{b}	9.8 ^{c}	12.4 ^{c}	<0.0001
Conjugated linoleic acid (*c9 t11*-CLA)	19.4 ^{a}	12.9 ^{b}	4.5 ^{d}	6.9 ^{c}	<0.0001
Alpha-linolenic (C18:3 n3)	10.2 ^{a}	7.8 ^{b}	5.0 ^{c}	2.8 ^{d}	<0.0001
Ratios of fatty acids					
*t*11/*t*10 C18:1	19.83 ^{a}	8.72 ^{b}	3.15 ^{c}	2.32 ^{c}	<0.0001
Omega-6/Omega-3	1.31 ^{d}	2.02 ^{c}	3.16 ^{b}	4.62 ^{a}	<0.0001

[1] N: number of observations; † Milk yield corrected 3.5% fat and 3.2% protein; Tl: day and night grazing; T2: diurnal grazing-barn supplemented; T3:grass-maize silage TMR; T4:maize silage TMR; Figures affected by different letters in the same row are significantly different.

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Theme 5.
Big data and smart technologies in grassland

A review of big data, smart and precision technologies in pasture-based dairying systems

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Abstract

This review assesses the drivers of performance technologies available and in development, data aggregation and application, decision support tools and economic considerations from the perspective of pasture-based dairying. The promised benefits of Precision Technologies (PTs) include improved efficiency, quality, animal health and welfare and reduced environmental impacts. To date, PTs have had a relatively modest impact in pasture-based dairying systems in comparison with other agricultural sectors, such as arable production. The large areas animals roam and graze in, in pasture-based systems and the associated connectivity challenges may, in part at least, explain the comparatively reduced use of such technologies in these systems. There are thus few technologies designed specifically to increase pasture utilisation with the exception of sensor and Bluetooth enabled plate meters. Terrestrial and satellite-based spectral analysis of pasture biomass and quality is still in the development phase. One of the key drivers of efficiency in pasture-based systems has only been marginally impacted by PTs. In contrast, technological development in the area of fertility and heat detection has been significant and offers potential value to dairy farmers. A past review concluded that, although accurate data was generally collected, the integration, presentation and decision-support application was generally inadequate with dairy cow fertility. As a result, it is unclear if farm management is being sufficiently improved to justify widespread adoption of PTs. We argue for a user need-driven development of technologies and for a focus on how outputs arising from PTs and resulting in decision support applications are delivered to users to maximise their value. Further cost/benefit analysis is also required to determine the efficacy of investing in PTs and what, if any, factors affect the variation in such analysis.

Keywords: pasture-based, dairy, big data, smart technologies, precision technologies

Introduction

Agriculture is changing and challenged by increasing globalisation, fluctuation in food prices, greater societal expectations, environmental constraints and policy changes, both at national and international levels. It has been estimated that demand for animal-derived protein may double by 2050 (Henchion *et al.,* 2017). Meeting this demand sustainably will, at a minimum, require producers to maximise production efficiencies while minimising negative environmental impacts, or in other words, developing increasingly resilient and sustainable agricultural systems. Many studies have reported that pasture-based systems of milk production have a distinct advantage over high input systems (Shalloo *et al.,* 2004; Dillon *et al.,* 2005), with grazing systems associated with greater global sustainability, increased product quality (O'Callaghan *et al.*, 2016), improved animal welfare (Wagner *et al*., 2018) and increased labour efficiency (Dillon *et al.,* 2005; O'Brien *et al.,* 2012). Though traditionally prevalent in areas such as the lowland of northwestern Europe, grazing is in competition with maize and renewable energy systems (Taube *et al.,* 2014), despite its strong economic and environmental potential. This potential is restrained by a lack of expertise and path dependency over the last century which has driven most European farms towards indoor and all year round calving systems. Increasing the efficiency and sustainability of pasture-based (and other) systems is thus desirable to make them even more competitive, especially in areas where the pasture-based system is currently a niche production model.

In this context, sensor technology development and application is increasing with 'Automation' and 'Big Data' now common in industry, society and science. The initial applications of sensor technology were mostly in robotics, defence and industrial production processes (Helwatkar *et al.,* 2014), but this is now expanding to most industries including agriculture. Many see this as integral to creating more resilient and sustainable farming systems in the future. The terms precision agriculture/livestock, smart farming and digital agriculture are now also familiar. The primary goals of precision livestock farming are to generate reliable data using biosensors and to process it to create value for the farmer, the environment and the animals (Neethirajan *et al.,* 2017). In order to produce added value, the data delivered by sensor systems (or retrieved from databases) needs to be translated into knowledge to facilitate automation or improved management decisions. The incorporation of sensors can thus be viewed as the culmination of a number of processes. The first is to measure the parameter of interest (e.g. pasture growth, quality, grazing cow behaviour) through sensors. The second step is to transfer the sensor data to a hub for integration. Sensor data is generally then converted to useful information through the generation of algorithms. Finally, when this data is integrated with other data/interrogated/ modelled, useful decision support information can be used to automate processes on farm (e.g. cow drafting / dynamic fertiliser application, etc.) or provided back to a user in an appropriate medium (Rutten *et al.,* 2013).

How information is delivered to the farmer and how the farmer applies this information is integral to the success of such technology (Banhazi *et al.,* 2012). In a review of sensors in health management for dairy farms, Rutten *et al.* (2013) noted that while the measurement part of systems largely functioned, the integration and decision-support elements were inadequate. As a result, while many relevant technologies are currently available, their value to farming systems is not clear (Steeneveld *et al.,* 2015). While precision technologies in farming promise increased efficiency, improved product quality, reduced environmental impact and offered overall improvements in animal health and welfare (Bewley, 2012), much has been slow to be realised thus far. This has been more pronounced in pasture-based systems, in part at least, due to the additional costs of connectivity across large grazing platforms but also partially because of the smaller market size and perceived demand relative to indoor milk production systems. Notwithstanding their reduced availability, the development of novel PTs to improve the performance of pasture-based systems, along with the adaptation of those presently available for indoor systems to pasture-based contexts would be advantageous to improve the productivity of pasture-based dairy farms in the future.

It is crucial that any farm investment strategy will increase the profitability of the farm business, with particular focus on increasing output through increased pasture growth and utilisation (Shalloo *et al.,* 2011), with previous research reporting significant potential for improved efficiency within pasture-based systems in Ireland (Creighton *et al.,* 2011; Kelly *et al.,* 2013). Technological solutions which can increase the utilisation of pasture and the productivity and fertility of seasonal calving herds are likely to add significant value to pasture-based systems. There is, however, a risk that technologies developed in other contexts will be marketed to farmers in pasture-based systems where their utility is marginal and their efficacy reduced. A focus on technologies that meet clear needs at the farm level (e.g. pasture quality assessment) will provide real benefits in profitability, sustainability and resilience by providing informed, real-time solutions to the farmer through an appropriate medium.

At a more aggregate level, PTs could also provide a platform to quantify, in a robust fashion, the sustainability of pasture-based ruminant production systems through integrating existing databases, capturing new data and developing scientifically robust models (Egger-Danner *et al.,* 2007; O'Brien *et al.,* 2014). This would aid the achievement of national objectives in consumer protection, continuous quality assurance, the creation of natural and pathogen-free foods, reduced antibiotic usage and better animal welfare standards.

This paper will review the use of big data and smart technologies in pasture-based dairying systems across the following headings:
1. drivers of performance;
2. sensors in pasture-based dairying systems;
3. data aggregation and aggregate application;
4. farm decision support and automation;
5. economics of investment in precision-based technologies; and
6. needs-driven PT development.

1. Drivers of performance

How dairy production costs and dairy farm profitability vary by system has previously been investigated. As a feed source for livestock, the cost of pasture relative to pasture silage and concentrate has been reported as 1: 1.8: 2.4, respectively (Finneran *et al.,* 2010). In line with this, the efficiency of pasture-based systems has been found to be positive with pasture utilisation, grazing season length and pasture management and negative when associated with supplementation level (Shalloo *et al.,* 2004; Macdonald *et al.,* 2010; Läpple *et al.,* 2012; Ramsbottom *et al.,* 2015). Grass utilisation is thus the single greatest driver of profitability and efficiency on pasture-based dairy farms and, in particular, on those with a spring block calving pattern.

Across the spectrum of pasture and increased supplementation and total mixed ration (TMR) systems, the optimum calving interval is 365 days (Esslemont *et al.,* 2001). However, the relative importance of fertility is comparatively greater in seasonal dairy production systems (Veerkamp *et al.,* 2002; Shalloo *et al.,* 2014). In pasture-based winter milk systems, the quality of ensiled pasture will, for example, be important and so the development of technologies to help assess and improve the quality and/or reduce the cost of ensiled pasture would be valuable for all systems.

The fertility costs associated with reproductive inefficiency in dairy herds can be broadly divided into five main categories. These costs include the effects associated with:
- increased calving interval;
- increased culling (Esslemont *et al.,* 2001);
- increased labour costs;
- increased interventions; and
- reduced submission rates.

Synchronising the demand for feed with pasture growth patterns is a key benefit of a spring calving pattern where the peak herd feed demand is matched with peak pasture growth (Shalloo *et al.,* 2007). In other words, a compact calving period in early spring matches the peak intake demands of the cow to spring pasture growth. In pasture-based systems, the effect calving-interval is magnified as feed supply and herd demand must be aligned. This is the main reason why the economic impact of reproductive inefficiency is even larger in pasture-based systems compared with more intensive systems.

Boichard (1990) identified that additional inseminations, veterinary and hormonal costs, and a modification of current and subsequent lactations are usually partially or totally due to fertility issues. In addition to these costs which can be directly linked to reproductive inefficiency, there are indirect costs which can have significant implications for a dairy farm. These include the reduction in the expansion potential and or an increased likelihood of animals being purchased onto the farm. These outcomes are associated with reduced financial performance due to scale inefficiency and disease risks associated with not maintaining a closed dairy herd (Shalloo *et al.,* 2014).

Ultimately, if PTs can increase pasture utilisation and cow fertility and or reduce labour requirements and costs significantly, they will make a notable contribution to increasing the overall sustainability of pasture-based systems.

2. Sensors in pasture-based dairying systems

Sensor technologies can be characterised by the measurement method employed and what they are measuring.

Pasture specific sensors

Dairy farmers that rely on pasture as their primary feed source require accurate real-time measurement of pasture biomass and quality to optimise grazing and nutrition management. Research shows that every 1 t DM ha^{-1} increase in pasture utilisation increases net farm profit by €181 ha^{-1} (Hanrahan personal communication).

Technology designed specifically to increase pasture utilisation is currently relatively rare. With other crops such as maize and soybean, sensors are now routinely being placed in fields measuring the microclimate, spectral characteristics and small-scale differences in soil fertility to help improve crop management and productivity (Wolfert *et al.,* 2017). Sensors developed with a focus on improving pasture growth are still in development and as yet are not commercially available. As pasture utilisation is a key driver of profitability in such systems (Hanrahan *et al.,* 2017), these sensors, like pasture growth measurement tools, may offer particularly high returns to pasture-based producers.

Examples of technology that enable improved pasture utilisation include digitally enabled plate meters which streamline and automate aspects of collecting the data required to generate pasture budgets (French *et al*., 2015). These have an added benefit in that the skill and experience required is much less than when compared to visual assessments. Given the importance of measurement in managing and increasing pasture utilisation, plate meters can offer significant benefits for relatively modest capital investments. This can be combined with a GPS to log on to the location or a Bluetooth connection to a smartphone to communicate to an app or server to calculate pasture availability (French *et al*., 2015). Another approach is to measure the height of the pasture canopy without a plate resting on the pasture but this is less sensitive to pasture density and so less sensitive to biomass. Distance measurement in both plate and canopy height is usually done via ultra/micro-sonic sensors which measure the height of the canopy itself or of a plate resting on the canopy (Moeckel *et al*., 2017). While plate meter approaches provide a good estimate of biomass, to assess pasture quality, spectral analysis is an area promising quality estimates that are quick and efficient alternatives to lab-based assessments but no commercial applications are currently available. Be it handheld, drone or satellite-based, there is increasing momentum around spectral approaches (Sibanda *et al*., 2016).

Spectral analysis can be done with portable, aerial or satellite-based systems and a common approach is to develop particular wavelengths to create indices such as NDVI (Normalised Difference Vegetation Index) which estimate if vegetation is present or not by assessing the ratio of red and near-infrared wavelengths. The photosynthetically active range is between 400 and 700 nanometres which appear relatively dark in vegetation. Above 700 appears relatively bright as plants remit these wavelengths as strong absorption would not aid photosynthesis and result in overheating. The challenges include background soil effects, atmospheric effects, grazing impact and heterogeneity of species and variation in pasture growth stages/ proportion of senescent material in the canopy which disproportionately influence spectral data (Moeckel *et al*., 2017). Further to this, most studies have focused on measuring pastureland biomass in tropical savannahs via remote satellite sensing with less focus on temperate pasturelands (Moeckel *et al*., 2017).

Moeckel *et al.* (2017) reported combining an ultrasonic sensor with handheld hyperspectral sensor data and satellite-derived spectral data to measure canopy height. They found that the best predictions of biomass were early in the grazing season when pastures were more homogenous. As grazing season continued, issues such as pasture refusal post grazing resulted in variability in the sensor outputs which could not be accounted for when predicting biomass. The R^2 values achieved with biomass, however, indicate that further development is required before practical application in pastureland management is possible (maximum $R^2 = 0.52$). This may be improved by incorporating a plate meter to give a better estimation of density c ultrasonic distance measures from a metre over ground although plate meters already offer reasonable accuracy for biomass estimation.

Successful non-satellite based spectral approaches to estimate pasture quality in temperate intensively managed pasturelands were not found in a search of the literature. There has been some progress using satellite data to estimate pasture biomass using Synthetic Aperture Radar. One study of Irish pasture found that grass biomass could be predicted with an R^2 of up to 0.75, based on this approach (Ali *et al.*, 2017). However, this high prediction was only achieved periodically when conditions were right in 'coherent' paddocks. Highly coherent paddocks tended to have low biomass after mowing. Variables such as wind flattening tall grass and grazing or mowing thus complicated the interpretation of the satellite data, especially as biomass increased.

In summary, there is potential for remote sensing to automate the collection of pasture data such as biomass and quality but there are significant technical challenges to be overcome before such information can inform pasture management, and thus increase pasture utilisation.

Cow behaviour and status sensors

Cow behaviour such as movement, location, rumination and resting are important for herd management, most notably for heat detection. Several different approaches have been developed to measure various cow behaviours. Some systems use electrical signal sensors (Beauchemin *et al.,* 1989; Rutter *et al.,* 1997) or pressure sensors to detect jaw movements (Zehner *et al.,* 2017). Büchel and Sundrum (2014) showed that jaw movements are indicative of feeding behaviour.

Accelerometers are another common sensor on cows and can measure behaviours such as feeding and rumination. The position of those systems on a cow varies with head-, neck- ear- and leg- mounted devices available (Bikker *et al.,* 2014; Borchers *et al.,* 2016). Acceleration measured by 3-D sensors, usually attached to the animal's legs, can be used to measure locomotion activity (e.g. RumiWatch pedometer (Alsaaod *et al.,* 2015) or IceTag pedometer (Ungar *et al.,* 2017)). These measurements can give an insight into different events (e.g. heats, health, behaviour, etc.) as increased activity can be associated with oestrus events. Other technologies for heat detection are mounting activity sensors including tail paint, scratch cards, KaMaRs (KaMaR), and HeatWatch (CowChips) (Holman *et al.,* 2011).

As feeding behaviour differs when cows are grazing, the sensors which accurately measure feeding behaviour indoors, are unlikely to be as effective with grazing cows and thus, sensors may require adaption and recalibration for grazing cows. The research-based noseband sensor RumiWatch is capable of measuring detailed grazing behaviour such as rumination chews and grazing bites as well as rumination and grazing times (Werner *et al.,* 2017). Most commercial sensors that are used on farms for measuring grazing behaviour, use an accelerometer around the neck (e.g. Heattime® by SCR Engineers, Netanya, Israel (Molfino *et al.,* 2017) or MooMonitor+, Dairymaster, Tralee, Ireland (Werner *et al.*, 2017)), with some of these technologies showing extremely high levels of accuracy. Activity sensors in general (beyond the specific concern of grazing) are discussed in the next section.

Another aspect of interest is real-time cow localisation, which might be of particular interest in pasture-based systems. There are already a number of techniques to determine animal position indoors. One such system is the Smartbow ear tag which has been shown to have reasonable accuracy in determining cow location indoors (Wolfger *et al.*, 2017). Smartbow works by triangulating the location of cow worn ear tags with low-frequency signals which are detected by multiple receivers in the barn allowing triangulation (Smartbow ear tag, Weibern, Austria). It is also possible to localise animals via ultra-wideband technology (e.g. CowView, GEA Farm Technologies GmbH, Germany (Tullo *et al.,* 2016)). In pasture-based systems, the accurate measurement of the animal's position used to be limited to GPS-based tracking systems (Williams *et al.,* 2016), but other approaches that are less burdensome on batteries are being developed that generally use a combination of approaches.

Another area for improved dairy cow health management is the automated detection of lameness with sensor technologies. This is particularly relevant in larger pasture-based dairy farms where cows may have to walk large distances between the milking parlour and pasture. There are different approaches, such as a system attached to the cow, mostly pedometers (e.g. IceTag3D™, Icerobotics, Edinburgh, United Kingdom), walkover systems (e.g. StepMetrix®, BouMatic, Madison, WI, USA), and camera systems (Viazzi *et al.,* 2014). Van De Gucht *et al.* (2017) found in a survey study that a sensor attached to the cow was preferred by the end users, followed by a walkover system and a camera system. Some studies already demonstrate positive results for automated lameness detection, but in many cases, the animal must be critically lame to be detected. Beer *et al.* (2016) showed that it is feasible to differentiate lame cows (> 2.5 locomotion score) from non-lame cows with data gathered by a pedometer (RumiWatch). No such tools are currently commercially available.

Milk sensors

To date, electrical conductivity and changes in milk colour are the most common indicators for in-line monitoring of udder health. Electrodes are inexpensive and can easily be incorporated in-line. There is, however, relatively large variation in sensitivity and specificity. This may be explained by the strong influence of, for example, milk fraction, milk viscosity, temperature, and technical conditions on the measured result, which underlines the necessity for a clear measurement procedure and sensor calibration (Hogeveen and Ouweltjes, 2002; Brandt *et al.,* 2010). It is possible to measure milk quality parameters such as fat, protein, lactose and milk urea nitrogen contents among others based on in-line sensors. With this data, it is possible to assess the energy and protein supply cows are receiving as well as metabolic imbalances which are major health and welfare concerns in dairy cows and could facilitate improved utilisation of pasture. These milk quality parameters can be accurately measured (milk fat, R^2 = 0.95; milk lactose, R^2 = 0.83; milk protein, R^2 = 0.72; SCC, R^2 = 0.68) by a near-infrared spectroscopic sensing system (Kawasaki *et al.,* 2008) or additionally with optical methods, biosensors or sensor arrays. The accuracy of the sensor is generally a function of the sensor cost. An example of a commercially available product to determine milk progesterone concentration is the DeLaval Herd Navigator. The system is able to measure lactate dehydrogenase for detection of (subclinical) mastitis, milk urea to assess the efficiency of protein feed rations and β-hydroxybutyrate to indicate (subclinical) ketosis and/or secondary metabolic disorders (Dobson, 2016).

Sensor summary

In summary, technologies specifically targeted at improving pasture utilisation are relatively rare, and those which exist are generally at relatively early stages of development. Understanding and measuring cow behaviour at pasture, measuring pasture growth and quality and better management of cows and pasture will benefit from continued development of PTs.

3. Data aggregation and application

A database is a structured set of data held in a computer that is accessible in various ways. Databases come in many different types and structures and a full discussion of this is beyond the scope of this review. This section will discuss the current types of databases that exist in agriculture today, what they do and how they are linked. There are vast quantities of data collected and stored across a whole range of different aspects of agriculture. Most of this data resides in databases specifically designed to facilitate one form of functionality (e.g. regulation, disease epidemiology, sustainability, etc.). While that data fulfils its original purpose, linking it with other data collected for other purposes could dramatically increase the value of the data i.e. sustainability assessment (O'Brien *et al.,* 2014). Examples may include the use of animal identification information to help populate sustainability models or the use of activity data as an animal welfare indicator. Some databases are designed to monitor commercial farm data and in general, are designed to fulfil a specific farm business requirement. The development of the internet has allowed these databases to be stored remotely and linked with other databases.

From data to information

Raw data is generally of little use to users so the processing and summarising of data is a key aspect of PTs and these processes are done by algorithms. Algorithms can take a wide range of forms (for review, see Valletta *et al.* (2017)). At its most basic level, algorithms can report changes (e.g. changes in steps taken per day). Building on this, automated inferences are made based on the data. This could, for example, include predicting if a cow is in oestrus or not by drawing upon cow history (e.g. calving date). At a more developed stage, a recommendation to breed to or not could be made taking into account factors such as waiting period since calving and if a cow has been identified for culling. The sire to be used might also be suggested, taking into account available genetic information or breeding goals (e.g. older cows served for beef calves and younger cows served sexed semen to produce higher genetic merits in heifer calves). Ultimately, an algorithm could partially automate the process by informing the artificial insemination technician of the cow to be served and the sire to use without the farmer's active input (Figure 1).

Interoperability and linkages

Large quantities of data are generated on farm, stored locally or aggregated by government agencies and companies. In most cases, databases storing this were developed with limited applications in mind. However, there is a magnitude of potential uses for the data (e.g. milking machine companies sharing data with the genetic improvement organisations). Such scenarios could result in large benefits for the dairy industry. A key barrier is aligning the huge incentives for all stakeholders (especially farmers) involved to deliver benefits. Data generated by machinery is generally stored locally and only aggregated by the machinery manufacturer. Integration with other manufacturers' systems and agencies databases is the exception. Data formats and protocols are not standardised and consequently, data measuring the same thing from different systems will not be interchangeable. Sometimes data formats are deliberately protected inhibiting third parties reading the data. This has generally resulted in much of collected data's potential not being fully harnessed.

The ability of a sensor or system to work with other *in-situ* technologies such as ID or drafting gate systems is often crucial to making them viable investments. Requiring duplication of functions will, therefore, likely discourage farmers purchasing from smaller vendors but may result in more comprehensive PT applications rather than an *ad hoc* network of systems from different suppliers. Collaboration, protocols for interoperability, data formatting standards, open source and open data approaches may be required to realise the full potential of PT's.

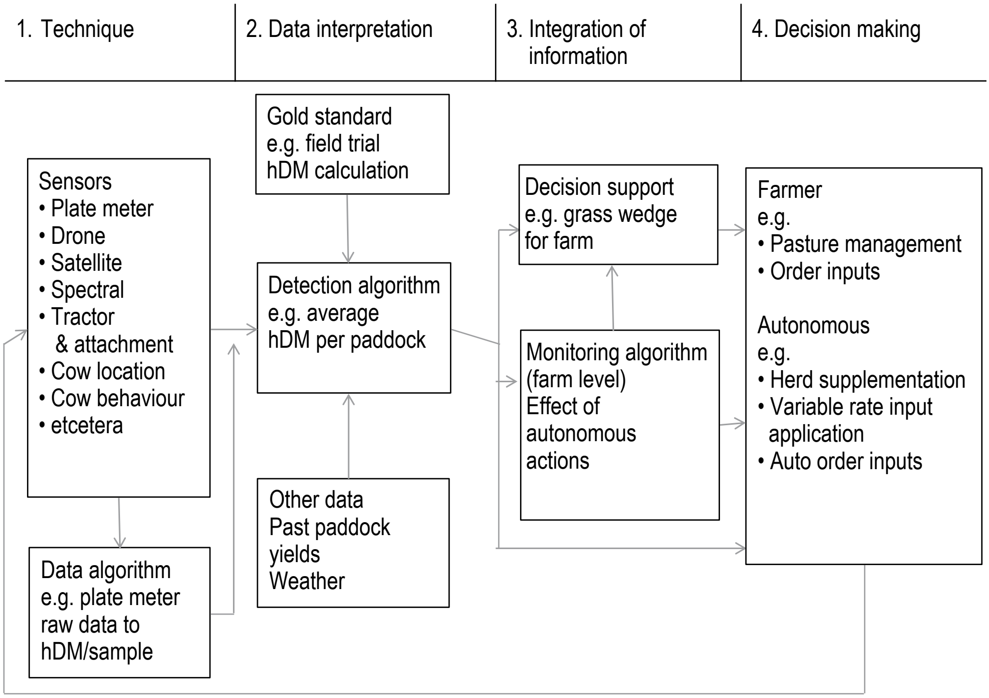

Figure 1. Schematic of stages of decision making and the use of sensor information in dairy farm management. Adapted from cow focused (Rutten *et al.*, 2013) to pasture focused.

To improve linkages between databases, there is a requirement to understand the design of existing databases including the database platform and infrastructure. The focus should centre on strategies to develop linkages between different databases. This process should identify issues around data integration and should ensure that any future developments in data collection can be undertaken using a standard methodology. The integration of data across relevant databases adds value to the analysis that may be completed as, generally, not all the pertinent data resides in any one database. For example, with every milk collection from a farm, there is an array of data collated (milk temperature, volume and time). Regularly, samples are taken for milk composition, milk hygiene and quality characteristics. Some of this data can now be used for management purposes.

Overcoming the barriers and challenges associated with data and intellectual property protection will be crucial. The challenges include data interoperability, sharing/access, proprietary systems and intellectual property concerns. In response to these challenges, major vendors have responded by creating company-specific ecosystems with good intracompany interoperability. This approach includes bundling/cross-selling of products.

Pastureland management databases

One such example in the area of pastureland research is PastureBase Ireland (PBI) (Hanrahan *et al.*, 2017). It builds on the concept of citizen science (Conrad and Hilchey, 2011). Citizen science has proved highly successful in the past in many countries, forming the bedrock of biological recording in various large research projects, particularly in ecology and environmental sciences. In the case of PBI, pastureland farmers are the citizen scientists collecting the pastureland data which is the data fuelling a new research program. This function is being achieved through the creation of discussion forums within the PBI system which allows for the roll-out of research and technology initiatives more easily, increasing farmer engagement.

Soil fertility

Data regarding fertiliser use on farm is generally stored with the merchant where the fertiliser is purchased. Protection of this data is important for many farmers and generally, they are unwilling to share it, harbouring concerns that any disclosure of this data might be used against them (e.g. nitrates regulations, land values). The potential benefits of centrally collecting and storing that data for sustainability assessments or at individual paddock levels to determine fertiliser response functions is significant. Ideally, if the farmer uses an app linked to a smartphone to record fertiliser information (spreading dates, quantities), this information can be automatically integrated with the pastureland database like PBI. This simplifies recording and improves the utility of the data for the farmer.

Animal genetics and health

Veterinary use of medicines (especially antibiotics), is regulated in most countries with the recording of information regarding diagnosis and treatments being a common requirement. The quantity and type of medicines administered to individual cows could potentially be stored in a central database. However, in most countries, while this information has been systematically recorded on paper, it generally has not been recorded electronically and has not been collated centrally (Egger-Danner *et al.*, 2012, 2007). One example of a country where a significant effort has been put into standardising and aggregating animal health data relating to dairy cows is Austria. In Austria, the recording of animal health treatments was made a legal requirement in 2002 but the form and coding of this recording were not standardised nor aggregated (Egger-Danner *et al.*, 2012, 2007).

In relation to animal genetics, there are a number of databases that are critical to increasing herd genetic merit (e.g. International Committee for Animal Recording Interbull Database; Irish Cattle Breeding Federation Database). Such data can be collected by public companies or associations (Ireland, Italy, etc.) but also by private genetic companies. Information regarding animal performance including milk yield, fertility, longevity, animal health, administered treatments, calving, etc. is routinely recorded. Precision technologies offer huge potential to inform breeding programs through the automated collection of phenotypic traits such as activity and behaviour, which may be of economic value to select for, within a breeding program. An example might include monitoring activity data that is collected by devices on individual animals as well as diagnoses of illness. Many of the traits that these devices collect information on are heritable, and it makes practical sense to record in order to improve future breeding programmes.

4. Farm decision support and automation

The primary objective of using a PT is to inform humans (or facilitate automated) decision making on farm. In many cases, human discernment and knowledge cannot be substituted by machines, so autonomous decision making is not always possible. Precision technologies can be categorised by the number of stages of decision making automated for the farmer. Rutten *et al.,* (2013) described four stages of decision making as a way to characterise how PTs integrate into decision making on farm. Figure 1 presents an adaptation of Rutten *et al.* (2013) schema to a pasture-based perspective. These four stages were data collection (technique), data interpretation, integration of multiple data sources and decision making. In many circumstances, automated decisions may be desirable where operator decisions may not practically be able to fully consider and interpret the data, and/or automation saves the farmer time or labour. As the amounts and types of data available, in addition to the multiplicity of automated decision implementation methods developing, this will become more relevant.

In systems that rely on the operator to make and implement decisions, information is made available to them via an interface, report or notification. The format and timeliness of how the information is provided affect the subsequent decision-making process. Some systems have algorithms and interfaces developed specifically to support decisions. Others only collect and report data and or cannot link different data sources inhibiting aggregation of relevant information in one view or report.

Decision support systems

To date, literature about decision making with precision technologies is sparse, especially regarding pasture-based dairy systems. Robustness of data collected by sensors is still perceived as a priority and thus, most research focuses on sensing accuracy and systems validation. Decision making remains pivotal to the successful application of PTs because it determines the value of a PT for the farmer (Hostiou *et al.,* 2017). In recent years, a few significant PTs have become available for pasture-based dairy operations, potentially generating a wealth of data regarding pasture, animal health and milk production.

Pasture

Decision Support Systems (DSS) for pasture management are available that utilise pasture as a major source of feed for dairy cows. Such technology facilitates improved pastureland management, delivering tangible benefits in terms of pasture supply, quality and utilisation (Creighton *et al.,* 2011; Hanrahan *et al.,* 2017) and ultimately, profitability (Shalloo *et al.,* 2011). The main features of the pasture management tools include the pasture wedge, pasture budget and the spring and autumn rotation planners. Such tools assist farmers in short to medium term pasture management (Macdonald *et al.,* 2010). Some DSS can also use historical pasture growth data to estimate pastureland production capacity and aid long term management decisions like determining the most suitable stocking rates and plan paddock reseeding, which have been found to be strictly related to the economic performance of pasture-based dairies (Kennedy *et al.,* 2007; Shalloo *et al.,* 2011; McCarthy *et al.,* 2013).

Herbage data such as farm average pasture cover in a given paddock are usually captured manually by the operator using a specific interface. Recent developments in information technology have allowed the development of automated pasture cover sensing (e.g. web-enabled Rising Plate Meter) with a mechanism to upload the data automatically via the cloud (McSweeney *et al.,* 2015). Most DSS for pastureland management now exist in the form of web-based applications. These provide greater flexibility to the user; web-based architecture enables the collation of large quantities of data in central databases which extend DSS functionalities beyond farm level. Data collected on a wide number of farms can be used to benchmark performance of a single operation, but also for research purposes and policy formulation (Hanrahan *et al.,* 2017).

Health and fertility

Over the last few years, automatic heat detection systems have become available on pasture-based operations. In some cases, data collected by heat detection systems are integrated with other information regarding the cow (e.g. stage of lactation, fertility status, milk yield, etc.) to provide better decision support information like whether or when to inseminate a cow or culling decisions (Mottram, 2016). Several DSS have been developed around reproductive management in dairy farms (Giordano *et al*., 2011; Rutten *et al.,* 2016), and some focused on pasture-based production systems (Beukes *et al.,* 2010; Fenlon *et al.,* 2017). These DSS have not been connected to any sensor systems.

Automation

The clearest example of PTs and automation lie in AMS based systems, which utilise data coming from a wide number of sensors to make autonomous decisions. Another example includes automated cow drafting systems using integrated information to autonomously separate cows that need specific attention and which adds significant value to many other sensors installed on farm (Wagner-Storch and Palmer, 2002). Another autonomous decision making technology that may find application in pasture-based farms is individualised feeding. The integration of sensor information with in-parlour feeding systems can offer each cow different amounts and types of concentrate according to specific parameters. These kinds of automatic systems are generally known as feed-to-yield systems since individual milk yield is usually the only parameter considered to calculate the amount of feed offered. In pasture-based farms, individualised feeding systems are usually installed in the milking parlour. On AMS, individualised concentrate feeding is standard (Bach and Cabrera, 2017).

Decision making deserves further attention in future research as it is key to maximising benefits of precision systems (Rutten *et al.*, 2013). As new and improved sensing technologies are developed, there is a growing need to foster the process of integration of information as it forms the base for sound decision making. The employment of an open and standardised data format to enable data exchange among precision systems is, therefore, strongly desirable. Advances in the fields of data analytics and computer modelling are expected to facilitate robust analysis systems capable of processing data from several sources. Improvements in DSS and autonomous systems are also expected.

5. Economics of investment in precision based technologies

Although PTs have been widely recognised as a potential route to improve productivity and sustainability of animal husbandry, acceptance and diffusion of such technologies in pastoral dairy production systems has been limited. Pasture-based farms are known to be low input systems where investments need to be carefully evaluated in order to maintain low costs of production. Uncertainty of the cost/benefits of some PTs is likely to be one factor limiting adoption (Neethirajan *et al.,* 2017). In numerous studies, PTs are presented as a way to improve farmers' quality of life by reducing working time and alleviating the burdens associated with farm management tasks. Such benefits often remain theoretical as the adoption of precision systems can generate new, intellectually demanding and time-consuming tasks. This is especially true if aspects of the system, such as data presentation and decision support, are poorly implemented (Hostiou *et al.,* 2017). Another limiting factor for the uptake of PTs in dairy farms is the lack of interoperability (real or perceived) between different data sources and software packages, which restricts integration of information, and thus the value and decision-making capabilities of precision management systems (Aubert *et al.,* 2012).

The efficacy of a novel PT will usually be unclear for a period after it becomes commercially available. Over time, successful tools tend to be validated by independent research organisations. Even if a tool has been shown to be technically effective, for example, accurately detecting oestrus, it may, however, not be economically viable. Potential factors influencing returns from technologies include cost, reliability/robustness, ease of use, farm circumstances, user's ability and interest. These aspects have rarely been included formally along with assessments of technical efficacy and are crucial to determining the mid to long term benefits of a PT.

Investment in decision supports

For dairy farmers, it is difficult to estimate the economic impacts for most technologies in advance of adoption. The risk of expensive technologies delivering poor financial returns to farmers is significant. One of the few studies that investigated this aspect found that sensors did not deliver a discernible return to Dutch dairy farmers between 2008 and 2013 (Steeneveld *et al.*, 2015). They compared three categories of dairy farms, conventional milking systems with no sensor technology, conventional milking systems with sensors (usually cow activity sensors) and automatic milking systems (AMS). The AMS systems were significantly less profitable than conventional farms with sensors with profit per 100 kg of milk dropping from €3.86 to €1.31. Contrary to expectation, the reduction in profit was mostly attributable to higher depreciation costs and comparably small reductions in labour costs by the authors.

No statistically significant difference in productivity could be found before finance costs could be discerned between conventional systems before and after installing sensor systems, although profit was slightly higher on average after installation (increasing from €5.11 to €6.16). This indicates, on average, a neutral or very modest return on investment for the average farmer in the study.

Sensor technology has advanced since that study with, for example, increasing performance of activity sensors (Steeneveld *et al*., 2017; Werner *et al*., 2017) and advanced techniques such as machine learning applied to activity monitors to add additional value such as the potential to predict/ detect calving (Borchers *et al.,* 2017). Returns may have also improved as technologies and knowledge about them improves. There may, however, be significant variation in the returns achieved which can be attributed to variation in farms, farmers and technologies invested. Consequently, there will continue to be a proportion of farmers investing in technologies which are not delivering good financial returns. Replicating these findings in a pasture-based dairy system and establishing the reasons for variation in investment returns would add to the literature. Advice and knowledge arising could also improve investment decisions by farmers. Firstly, it would guide vendors to better target their research, development and marketing of technologies. Secondly, farmers would have more insight as to which combination of technologies and farm situations deliver the best returns.

Why some farmers benefited financially while others did not, from investing in the Dutch dairy farmer study (Steeneveld *et al.,* 2015), has not been appropriately answered. Farmers will be rightfully cautious about technologies until this is clarified further. In so doing, they will be likely to overlook specific technologies which offer higher likelihoods of economic benefits. This information gap is a major issue as the adoption rate of PTs is low (Steeneveld *et al.,* 2017). In light of this, increased knowledge of the drivers of adoption rates can also be used to increase average returns. While the drivers of good returns from technology investment are relatively unknown, there is a wealth of literature on the motivations of farmers to invest in a technology or adopt specific management practices (Edwards-Jones, 2006; Garforth *et al.,* 2006; Rehman *et al.,* 2007; Garforth, 2010; Jones *et al.,* 2016).

Traditional decision support tools generally take traditional forms such as Microsoft Excel, Visual Basic Interface Excel, webpages or standalone software programs. They help farmers to improve outcomes or guide difficult decisions around a specific topic, e.g. mastitis. The data is generally entered manually by the farmer or the advisor and they don't rely on precision agriculture or big data (Geary *et al*., 2014). A search of the literature did not uncover any currently available tools focused specifically on assessing investments in PTs. Developing such tools was previously mentioned as a primary objective in one study (Bewley *et al.,* 2010) and would be of significant value to farmers, advisors and vendors, creating clear information that will assist the decision making process.

Ultimately, the economic return on investment in PTs is variable. It appears that, in general, pasture measurement technology and heat detection tools have a strong economic rationale. More generally, as it is difficult for farmers and researchers alike to discern good and poor investments, cost/benefit analysis of novel technologies is required, in particular, on the areas with greatest potential for financial impact (Bewley *et al.,* 2010).

User attributes

Despite improved information provision, decision making can still be poorly implemented in part due to variation in management capacity to review and interpret the data (Rutten *et al.,* 2013). User attributes may thus have a major impact on the return derived from technologies. Few technologies interpret data and it is rarer still for technologies to automate decision making (Rutten *et al*., 2013). For this reason, it is often the case that a technology may only provide information. Whether or not that information is in fact acted upon will likely depend on the user's time availability, attitudes, personality and general ability and understanding in addition to the degree of technology specific training received.

O'Leary *et al*. (2017a, 2017b) assessed the associations between profitability and farm manager attitudes and personality. 'Growth mind-set' and 'detailed conscious' competencies of dairy farmers were both strongly associated with profitability ($R^2 > 0.4$). Those with a growth mind-set believe they and others' abilities are malleable and are, therefore, likely to continue learning regularly (Visser, 2013). A high scorer on 'detail conscious' 'focuses on detail, likes being methodical, organised and systematic'. A low scorer is 'unlikely to become preoccupied with detail, less organised and systematic and dislikes tasks involving detail'.

Similar to 'detail conscious' in particular, Bewley *et al*. (2010) proposed a 'best management practice adherence factor'. This estimated the impact of the degree a farmer acts on data generated and has a huge impact on the modelled returns for oestrus detection and BCS assessment tools. These findings are likely to have implications for which farmers may benefit most from technologies. Those that have a growth mind-set may be more likely to invest more time in experimenting, learning about and trialling new technologies. Those that are more detail conscious will likely review, interpret and act on the data arising from PTs more diligently. Matching PTs appropriately with users and/or providing sufficient training so that users get the most value from PTs will thus be important.

6. Needs-driven PT development

One critique of the current nature of PT in agriculture has been the prevalence of taking of existing mature technology from other sectors (solutions) and then looking for a potential application of these on farm.

Kruger and Cross (2006) define solution driven design as when:

> *The designer focuses on generating solutions, and only gathers information that is needed to further develop a solution. The emphasis lies on generating solutions, and little time is spent on defining the problem, which may be reframed to suit an emerging solution.*

Here the solution is more important than the problem or need being solved which only becomes relevant at later stages of the process. Kruger and Cross (2006) contrast this with problem driven design which they defined as:

> *The designer focuses closely on the problem at hand and only uses information and knowledge that is strictly needed to solve the problem. The emphasis lies on defining the problem, and finding a solution as soon as possible.*

We introduce the concept of Need Driven (ND) development as a useful paradigm for the development of PTs. Indeed, ND is similar to Problem Driven design but broader in scope and entails developing and delivering technologies to meet clearly defined needs rather than trying to repurpose technologies from another context. For example, it includes needs such as increasing labour efficiency which might not be classed as a 'problem' *per se*. We believe the ND approach and focusing on tangible improvements in profitability, sustainability and resilience is key to the success of PTs to sustainable pasture-based systems. We propose that ND technologies are those providing informed and real time management aids to the farmer. Further, we characterise ND technologies as those delivered in ways that are comprehensible and relevant to the farmer. The third key characteristic of ND technologies is that they contribute data to essential research programmes such a performance evaluation, animal and pasture genetics (Egger-Danner *et al*., 2012, 2007). Finally, as defining and implementing sustainability remains a major challenge, ND technologies will contribute to a platform to quantify the sustainability of pasture-based ruminant production systems. However, the technologies must be capable of standing on their own by providing justification for their investment directly back to the farmer.

This proposed sustainability platform will integrate existing databases and capture the data emerging from novel ND technologies. International objectives around consumer protection, quality assurance may also benefit from an ND approach.

We venture that the key needs of pasture-based farming systems is transforming sustainability from a broad ill-defined concept to a clear and measurable construct. We propose the concept of ND as a set of principles to guide and expedite the achievement of PTs potential in pasture-based livestock ruminant production systems.

Within sustainability, we further specify the following as priority areas:
- economic resilience (adding value to products, reducing costs, increasing efficiencies);
- labour shortages (automation);
- management ability (improving the skills of managers for an increasingly complex role);
- animal health (e.g. udder health, fertility, lameness, etc.);
- welfare (the five freedoms);
- environmental measurement and benchmarking.

Conclusion

Precision technologies offer significant potential to increase efficiency, reduce costs and labour, increase sustainability, improve sustainability verification and raise animal welfare standards of pasture-based systems of milk production. The integration of sensor data, collated within centralised databases enriched with existing data and analysed for specific end use requirements with outputs provided through appropriate media and in real time fashion, will alter the use of these technologies in pasture-based farming. A key shortcoming to date in this area is the failure to add value to data collected as the focus has been on accuracy. Farmer's time is limited and their skills and capabilities are variable. Designing tools and products with these factors in mind will improve tools impact. For big data and smart technologies to realise their potential in agriculture, there is a requirement for the various industry stakeholders to work together to create a consensus regarding the main industry needs and to subsequently develop platforms and infrastructure that can maximise the potential of PT's. The key drivers of efficiency and profitability in pasture-based systems are pasture utilisation and dairy cow fertility. Technologies that advance these components of the business have the greatest chance of delivering a positive return for the end user.

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Influence of pasture characteristics and time of day on dairy cow behaviour predicted from GPS-data

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Abstract

The relationship between animal behaviour and pasture characteristics needs to be explored to facilitate pasture management. Using Global Positioning System (GPS) data, this paper aims to study the influence of pasture characteristics and time of day on (1) cow distribution in the paddock and (2) the main behaviour inferred in each area. Fourteen Holstein cows were tracked with GPS receivers mounted on collars for an entire day and were observed simultaneously. A vegetation cover characterisation (floral species and dry matter) and sward height measurements were carried out before and after grazing. Each of these measurements was also GPS located. A heterogeneous distribution of cows inside the paddock was observed. Using distances and turning angles, main behaviours (grazing, resting and walking) were predicted using a decision tree. Cows spent significantly more time resting in the afternoon than in the morning and frequently rested near the drinking trough. A greater difference in sward height between entry and exit of cows was observed in areas where resting was the main behaviour. These findings showed that cow time-budget can be studied efficiently without laborious observation using GPS-located resources and GPS data.

Keywords: global positioning system, cow, behaviour, pasture characteristics, decision tree

Introduction

Increasing the quantity of grazed grass in the diet may appear to be an attractive solution to reduce costs of production. However, an efficient use of the grass requires a system which maximises intake of grass at the best vegetative stage (nutritional value) and ensures the sustainability in terms of quantity and quality of grass production (Peyraud and Delaby, 2005). A better understanding of how cows use pastures, given the resources distribution (sward height, composition, vegetative stage) and the time of day, is a key point to optimising pasture management (Andriamandroso, 2017). Furthermore, global positioning system (GPS) technology is increasingly applied in livestock science and helps predict cow behaviour successfully (de Weerd *et al.*, 2015). Using GPS data, this paper aims to study the influence of pasture characteristics and time of day on cow distribution and on behaviours.

Materials and methods

The experiment was conducted in a commercial farm located in the Lion d'Angers, France, in the spring of 2017. The pastures used were temporary and sown with a mixture of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.). Fourteen Hosltein cows in a herd of 71 were tracked with GPS receivers (RF-track system with EVA-7M module from u-blox) mounted on neck collars which recorded a fixed position every second. Cows were milked every day at 9 am and 6 pm. To study the distribution of cows in the paddock, the density of cows was studied for a whole day, and each half day, by computing the percentage of cows located in each 3 × 3 m area with R 3.4.0 software (R Core Team, 2017).

In order to discriminate between resting, grazing and walking, a decision tree was calibrated using GPS signals with the associated observed behaviour, recorded by two observers for each cow successively, for an entire day. A pre-processing step was carried out with MATLAB 2016b software (MATLAB and Statistics Toolbox, 2016), during which a low pass filter was applied to prevent aliasing before a subsampling at 60 s. Data outside of the paddock, corresponding mainly to milking, were discarded (27.8% of the data). Then, distances and turning angles between each fixe were computed with the adehabitatLT package in R and the decision tree based on these features was calibrated using rpart package in R.

The distribution of behaviours in the paddock and the variations between the morning and the afternoon were examined on a further day of the experiment in another field. GPS-data were pre-processed in the same way as previously and behaviours were predicted using the calibrated decision tree. A chi square test was performed in R to compare the distribution of activities per half day (of this day) of experiment.

Finally, a focus was placed on the link between predicted behaviours and resources distribution. To respond to this issue, GPS-located sward height measurements were made before and after grazing (1000 measurements ha^{-1}) with the electronic plate-meter Grass Hopper® (TrueNorthTechnologies, Shannon, Ireland). Samples of vegetation cover were also collected (250 measurements ha^{-1}) and GPS-located with the Google application Quick Position Save. The ratio of perennial ryegrass (*Lolium perenne* L.), white clover (*Trifolium repens* L.) and self-propagating plants were determined in each sample; other species were regarded as negligible. The percentage DM was also obtained according to Delagarde *et al.* (2016). Then, numerical maps were obtained for each pasture characteristic using QGIS 2.18.9 (QGIS Development Team, 2017) and ArcGIS Desktop 10.0 (ESRI, 2010) software in order to explore the link with predicted behaviours using a Permutational Multivariate Analysis of Variance (permanova).

Results and discussion

The dispersion of the cows over the paddock area was heterogeneous, with some areas avoided and others being frequently visited, such as close to the drinking trough (Figure 1a). A satisfactory calibration of decision tree was obtained with a misclassification rate of the behaviours of 10% using training dataset, and of 13% using 10-fold cross-validation. As expected, resting, grazing and walking were successfully predicted based on distance and turning angle (de Weerd *et al.*, 2015). A filter imposed by the resampling process was applied, which may explain the improvement as compared with de Weerd *et al.* (2015).

Cows seemed to organise their activities inside the paddock (Figure 1b). The time-budget was significantly different between each half day ($P < 0.0001$), with 52.2% of grazing and 47.8% of resting in the morning versus 41.6 and 58.4% in the afternoon, respectively. Cows grazed uniformly on the paddock during the morning and gathered near to the drinking trough for resting during the afternoon. However, this was more likely related to heat stress (temperature higher than 30 °C during this afternoon) than to the distribution of resources.

No significant relationship between behaviour and pasture characteristics (DM and floral distributions) was observed. However, a greater difference in sward height was observed where the cow density was higher, which is in agreement with Tonn *et al.* (2016). This also coincided with areas where resting was the main behaviour (45.4 vs 39.9% for the others, $P < 0.0001$). This result suggests either that the area near to the drinking trough was quickly grazed at the beginning of the day, or that the grass was trampled during the afternoon. The lack of relationship between behaviour and pasture characteristics could be related to the grazing management (one-day paddock of 0.33 ha for 71 cows with a corn silage supplementation, temporary homogeneous pasture planted with only two species), or to our methodology (only 14 cows were tracked on a herd of 71).

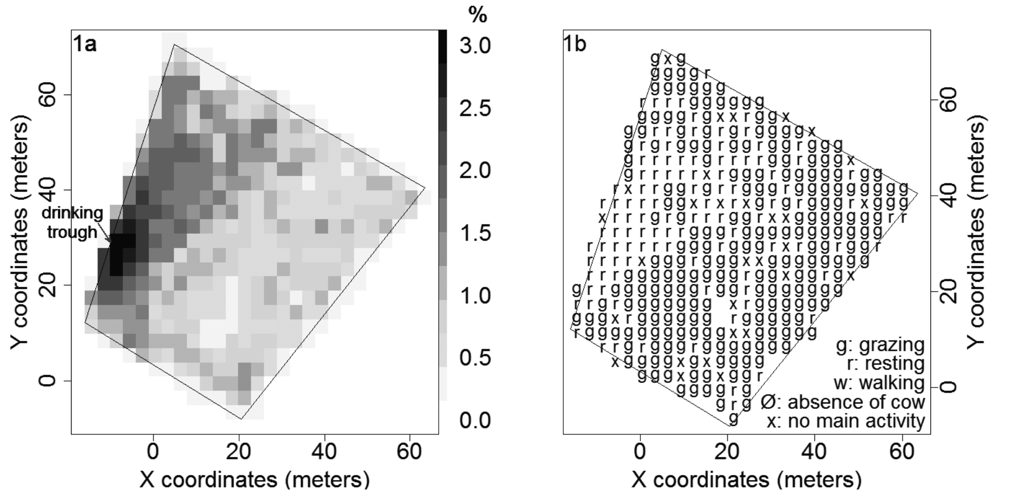

Figure 1. (a) Distribution of cows (%) inside the paddock for the entire day, obtained by counting the number of cow positions inside each 3 × 3 m area. The darker areas of the square are associated with more frequent cow visits. (b) Dominant behaviour in the same 3 × 3 m area was predicted with a decision tree.

Conclusion

The distribution of cows over the paddock area was heterogeneous, change over time was observed and some areas seemed to be preferentially used for resting or grazing although no relationship between behaviour and pasture characteristics could be well-defined. The present study can be improved in merging GPS with other sensors in order to identify and evaluate more activities. The link between behaviour and resources needs to be explored in a more favourable context for feeding behaviour expression, namely with more floral diversity, greater space and grazing time (continuous grazing), without supplementation.

Acknowledgements

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A partial budgeting tool to assess investments in precision dairy technologies

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Abstract

The technical efficacy of novel Precision Dairy Technologies (PDTs) is generally not independently verified for a period after commercial release. Subsequent to independent technical validation, the economic benefits of PDTs might be independently estimated. As such it will usually take years from the PDT reaching the market until an independent economic analysis is performed, if at all. It is, thus, usually difficult to estimate the likely Return on Investment (ROI). This study describes a flexible decision support tool designed to ameliorate this difficulty using a partial budgeting approach. Taking the PDT's cost and desired ROI, the reduction in costs and increase in income required to achieve this ROI is estimated. Associations between productivity indicators (e.g. six-week calving rate) and changes in costs/income are then used to estimate the technical improvement required to deliver the ROI. This estimate is likely to be extremely valuable for farmers, advisors and vendors during the investment decision-making process. Vendors will benefit by being able to better demonstrate the value of their PDT, potentially facilitating increased adoption of PDTs. By using the decision support tool, improved use of limited farm business capital is expected, ultimately resulting in increased returns for investments made at the farm level.

Keywords: precision dairy, decision support, return on investment

Introduction

Once a Precision Dairy Technology (PDT) has been shown to be technically effective, for example, accurately detecting oestrus, it may still not be economically viable. Key factors influencing returns from PDTs include initial costs, reliability/robustness, ease of use, farm circumstances and PDT user's attributes. Studies of these factors are much rarer than assessments of PDT's technical efficacy. For dairy farmers, it is thus difficult to estimate Return on Investment (ROI). The economic return of PDTs has been variable (Steeneveld *et al.,* 2015) and, in general, heat detection PDTs have a strong economic rationale (Steeneveld *et al.,* 2017). For other precision technologies, such as body condition scoring cameras and automatic milking systems, the case is not so strong (Shortall *et al.,* 2016; Steeneveld *et al.,* 2017). The risk of technologies not delivering financially to farmers is therefore tangible.

One study indicated that sensors, on average,were not associated with a statistically significant improvement in performance by Dutch dairy farmers between 2008 and 2013 (Steeneveld *et al.,* 2015). This study indicated that the average farmer who invested in sensors was slightly more profitable to begin with (€5.11/100 kg) than those that did not invest (€4.07/100 kg). Those that did invest increased profitability on average from €5.11 to €6.16 but this improvement was not statistically significant; the economic benefit was likely to have been variable. The main factor influencing the variability in returns from investment in PDTs between farms is unknown. Most farmers will thus be justifiably cautious about PDTs until this is clarified. This has the negative consequence that good investments may be overlooked and may influence the low adoption rates of PDT (Steeneveld *et al.,* 2017). Consequently, the potential performance of farms and the dairy industry may be curtailed.

Farmers considering investing in PDTs are dealing with varying levels of incomplete information. Currently, independent researchers validate the technical performance of newly developed sensors and might model the likely economic returns of individual PDTs. However, a broader approach may be beneficial. A decision support tool could be developed in which information is aggregated to assist farmers in making more informed decisions about PDT's.

Decision support tools can be created in a range of formats such as Excel, PDF, website or a stand-alone software program. Decision support tools have traditionally been designed to help farmers to improve outcomes or guide difficult decisions around a specific topic, e.g. mastitis management. Often, a partial budgeting approach is taken to assess investments or changes in practice. This has been carried out for interventions to improve herd health, for example (Hogeveen *et al.,* 2016). A decision support tool specifically designed for investing in precision technologies may be of significant value to farmers, advisers and vendors of PDTs (Bewley *et al.,* 2010). We report the development of such a decision support tool here.

Materials and methods

A partial budgeting tool called Precision Dairy Cost Benefit Tool (PDCBT) v0.1 was created in Microsoft Excel 2007. The initial user inputted data on the cost of the PDT and the ROI the user requires to justify the investment. The associated annual improvement in reduced costs or increased income required to achieve this is then estimated by the tool. From published literature, research experiments, models and expert consultation, estimates of the associations between productivity indicators (e.g. grass utilisation ha^{-1}) and changes in costs/income were collated. Using these assumptions, the improvement in technical performance required to achieve the target is then estimated.

The PDT's general efficacy or how the farmer is likely to use it, for example, is not a required input. As this information is rarely available and is difficult for farmers to estimate, this is a key benefit of the tool's unique approach. The decision support tool estimates what change in technical performance is likely to be required to justify the investment. If this level of technical performance improvement is realistic or not must be judged by users. This need for judgement is the status quo, but the scope of judgement required is reduced by using the tool.

In the case of a lameness detection PDT, if a reduction of 25% of total herd lameness is required to justify investing economically, and the herd's current rate is 20%, then the tool can only achieve 5% short of the required lameness correction level. It would, therefore, represent a poor economic investment. Conversely, if a grass management PDT only needs to deliver a 50 kg DM ha^{-1} improvement in grass utilisation, this may indicate a good investment. This is a relatively novel approach and it also appears to be appropriate for novel and fast developing technologies.

The PDTCB consists of 10 Excel sheets, the names of nine of them and how a user progresses through them are illustrated in Figure 1. The tenth sheet details the assumptions used and sources for these assumptions. A user progresses through a maximum of six sheets when using the tool. Users input a maximum of 11 variables and select from several pre-set options. This, combined with its intuitive structure and clear instructions, make the tool quick and easy to use. A returning user will require less than five minutes to use the tool. A first time user will likely require 15 - 20 minutes to read the instructions, input their data and generate useful estimates. Beta version 0.1 is available at https://goo.gl/Lncgqm (copy and paste/type into the browser). Readers are invited to test the tool and can provide feedback to inform future development through a link in the tool.

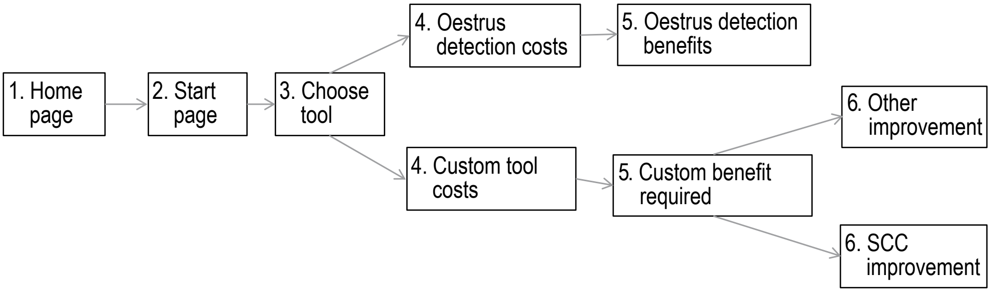

Figure 1. User progression through the decision support tool.

Results and discussion

The presented decision support tool is relatively quick and easy to use. It is designed to frame investment decisions relating to PDTs in a way that limits the scope of judgement required when making investment decisions and ultimately to improve the ROI to farmers. Vendors will also benefit by having an additional method to demonstrate the value of PLTs. Initial responses by a small number of farmers have been generally positive but further trialling and development is required (e.g. including additional pre-set options).

Conclusion

Farmers investing in PDTs often have incomplete information about a PDT's efficacy, likely economic returns and how they themselves will use the PDT. However, use of the reported decision support tool by farmers and advisors would allow improved use of limited farm business capital, by framing the investment decision in terms of what improvement in technical performance is required to justify a particular investment.

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Multi-temporal estimation of forage biomass in heterogeneous pastures using static and mobile ultrasonic and hyperspectral measurements

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Abstract

Efficient feed production from grassland, including grazing and harvesting for forage conservation, requires constant monitoring of total farm grasslands to ensure consistent animal production. Ground based remote sensing technologies have been recognised as a practical methodology to estimate various vegetation parameters at the field scale. Particularly, the combined use of e.g. spectral sensors and ultrasonic sensors might be of interest for the prediction of vegetation biomass in heterogenous pastures. The aim of this study was to evaluate the applicability of ultrasonic and hyperspectral mobile measurements to map spatial and temporal yield variation, over two consecutive years, in heterogeneous pastures. Field measurements were conducted at five sampling dates between April 2013 and May 2014 in three pastures with different grazing intensities (extensive, lenient, very lenient). Multivariate regression methods and Kriging interpolation were used to develop prediction models for fresh matter yield for every sampling date and grazing intensity. The results suggest that mobile multisensory systems can produce acceptable accuracies for forage quantity assessment in extremely heterogeneous grasslands. However, the prediction error increased towards the late successional stages due to the increasing cover of dead material. Mobile systems may facilitate mapping of larger grassland areas at high spatial position accuracy, allowing the identification of nested structures within the pastures.

Keywords: grassland, remote sensing technologies, spectral sensors, ultrasonic sensors

Introduction

Feeding of livestock on pasture requires constant monitoring of forage quantity to ensure consistent levels of animal and milk production (Oudshoorn *et al.*, 2013). Mobile and time-efficient systems are needed for assessing forage biomass and its spatial distribution in pastures. This information can help livestock managers in making critical decisions in terms of grazing time, grazing period and stocking rate and supports site-specific pasture management (Suzuki *et al.*, 2012). Ground based remote sensing technologies have been recognised as a practical means to estimate various vegetation parameters at the field scale. Particularly, the combined use of e.g. spectral sensors and ultrasonic sensors might be of interest for the prediction of vegetation biomass in heterogenous pastures (Möckel *et al.*, 2017). The aim of this study was to evaluate the applicability of ultrasonic and hyperspectral mobile measurements to map spatial and temporal yield variation over two consecutive years in heterogeneous pastures.

Methods

The study was conducted in a long-term pasture experiment in Relliehausen in Central Germany. The *Lolio-Cynosuretum* pastures are moderately species rich. Three study plots (30 × 50 m) were established in three paddocks with different levels of grazing intensity (moderate with 3.4 ha^{-1} SLU, lenient with 1.8 ha^{-1} SLU and very lenient with 1.3 ha^{-1} SLU). Measurements in the study plots were conducted at four sampling dates (May to September) in 2013 and 2014. Each of the study plots was measured with a remotely steered sensor vehicle equipped with three ultrasonic sensors (UC 2000-30GM-IUR2-V15) and one hyperspectral spectrometer (Handyspec, tec5), resulting in ~1,700 measurement points. For each sampling plot and date 18 reference plots (each 50 × 50 cm) were established. In total, 430 reference plots were sampled throughout the two years. Fresh matter biomass was sampled within each sampling plot. The biomass data was checked for univariate outliers and seven outliers (1.6%) were removed from further analysis. The distribution of the biomass data was slightly skewed and, therefore, the biomass values were square-root transformed. For the reference plots, the closest spectral and ultra-sonic measurement value was extracted. From the spectral data, wavelengths with noise were removed, which resulted in remaining 1,090 wavebands used for model building. The spectral data was filtered using a Savitzky-Golay filter (window size = 11, order = 5) and a continuum removal was applied. The final model consisted of 423 samples and 1,091 explanatory variables. Using several machine-learning methods (random forest, support vector regression, partial least squares regression, and genetic algorithm partial least squares regression), the best multivariate model was identified. The prediction quality of the four models was evaluated using the cross-validated R^2 and RMSE values. The best model was subsequently used for predicting the fresh biomass for all mobile measurements. These nearly continuous measurement maps for each sampling date and grazing intensity were interpolated using an Ordinary Kriging interpolation. In each map the lowest (0 - 10%) and highest (90 - 100%) of the values were identified and classified as -1 and +1, respectively. The aim was to identify low and high biomass regions in each grassland. All sampling dates (four per year) for each grazing intensity were summed up. This allowed an identification of areas with a high temporal stability in biomass values.

Results and discussion

The best model for fresh matter yield resulted in a R^2 of 0.53 (ranging from 0.33 to 0.71) and an average prediction error of RMSE= 0.58, which corresponds to 13.5% of the range of the measured biomass in the reference plots. All three machine learning methods delivered similar results, but it could also be shown that a comparison of model performance can improve prediction quality of models.

Maps for each intensity are shown in Figure 1. The values range from -8, indicating a long continuity of low biomass values, to + 8, indicating a long continuity of high biomass values. The results show that independent of the grazing intensity, areas in each grassland exist which are preferred for grazing and other areas which are neglected by the animals. Remarkably, the patterns are visible, although data from eight sampling dates over a period of two years were examined. These results suggest that animals on pastures follow certain tracks for their grazing, and these tracks seem to be stable for more than one grazing period. The results are in accordance with the results of Rossignol *et al.* (2011), who developed

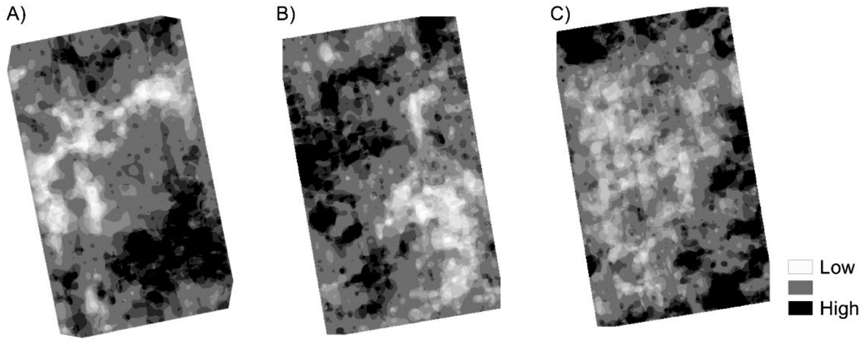

Figure 1. Yield maps for three grazing intensities (A: very lenient, B: lenient, C: moderate). Dark values indicating a long continuity of high biomass values. White indicates a long continuity of low biomass values. The values are based on four sampling dates within two years (for further details, see text).

a hierarchical model and identified a stability of grazing pattern within two years. To investigate the proportion of class values in all intensities, a cumulative curve was calculated for each intensity (Figure 2). The curve for moderate grazing shows that the proportion of area with a long continuity of low biomass values is lower than for lenient and very lenient grazing. This suggests a more homogenous grazing pattern for moderately grazed pastures and a higher stability of pattern of high and low biomass for the other two grazing intensities.

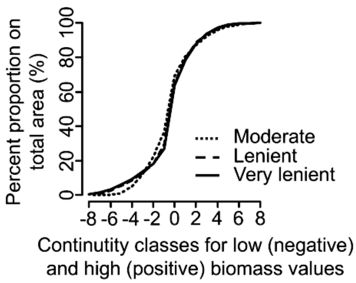

Figure 2. Cumulative curves of proportion of continuity class on total area for very lenient (solid), lenient (dashes), and moderate (points) grazing intensities.

Conclusion

The results of this study show that mobile sensory systems can be used to examine grazing patterns in pastures. The model accuracy for predicting the biomass was moderate but the resulting yield maps confirm the expectation about the spatio-temporal grazing patterns in pastures.

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Effects of biodiversity on ecosystem functioning in a grassland experiment (Jena) and implications for management

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Abstract

The Jena Experiment was set up to investigate the effects of grassland plant diversity on ecosystem functioning. Here, we shortly summarise selected results from 15 years of research. About 45% of the investigated ecosystem processes were significantly affected by plant species richness. Importantly, biomass production increased with plant species richness. Most organism groups responded positively to higher plant species richness, and effects on organismic diversity were stronger than on species abundances. The Jena Experiment also quantified effects of diversity on nitrogen (N), phosphorus (P) and carbon (C) cycling and the water balance of the plots. Combining many individual functions into a measure of ecosystem multifunctionality demonstrated that functioning as a whole increased with plant species richness. The results of the Jena Experiment suggest that diverse grasslands show high productivity while simultaneously providing multiple additional ecosystem services.

Keywords: ecosystem services, multifunctionality, plant species richness

Introduction

Biodiversity loss can affect ecosystem functioning and service provisioning. If biodiversity is needed for the provisioning of services by nature (e.g. production, maintenance of soil fertility, water purification, pollination), then this provides a compelling reason for conserving biodiversity (Millennium Ecosystem Assessment, 2005). As land-use is the main driver of decreasing biodiversity worldwide (Maxwell *et al.,* 2016), understanding how biodiversity influences ecosystem functioning and the delivery of services could pave the way for the sustainable management of ecosystems.

An important approach to investigate the causal effects of biodiversity on ecosystem processes is the direct manipulation of biodiversity as an independent variable (Weisser *et al.,* 2017). Such biodiversity experiments allow for a decoupling of plant diversity and environmental factors (e.g. site fertility), that often are correlated in nature. Grasslands are a particularly suitable model system for such experiments. Here we report results of the Jena Experiment, one of the largest and longest-running grassland biodiversity experiments worldwide that are of particular interest for grassland management.

Materials and methods

The Jena Experiment is situated on a 10 ha large area in the floodplain of the Saale river in Jena, Germany (50° 57’ 3.06’’ N, 11° 37’ 29.98’’ E, 130 m asl), with mean annual temperatures of 9.9 °C and precipitation of 610 mm. The site was used as a fertilised arable field before the establishment of the experiment in 2002 (Roscher *et al.,* 2004). Sixty plant species typical of semi-natural, species-rich, mesophilic grasslands comprise the species pool of the experiment. All experimental plant communities were sown with constant total densities and equal proportions of all species in the mixtures. The main experiment was established on 82 plots (20 × 20 m size) and manipulates plant species richness and plant functional diversity. The diversity gradient was created by sowing plant communities with random subsets of the species pool of a defined species richness level on a logarithmic scale (1, 2, 4, 8, 16 and 60) and with 16, 14 and four replicates of species levels 1-8,16 and 60, respectively. Functional diversity was manipulated by varying the number of functional groups (grasses, legumes, small herbs and tall herbs) present in a community (Roscher *et al.,* 2004). The biodiversity gradient was maintained by weeding in spring, summer and autumn. Over the years, a large variety of different ecosystem functions has been measured (Weisser *et al.,* 2017).

Plots were managed by taking two cuts per year, removing all biomass and maintaining without fertilisation. To test if the results obtained under this type of management, which is less intensive than many grasslands managed for high productivity, could be extrapolated to grasslands managed more intensively, a gradient in management intensity was established (Weigelt *et al.,* 2009). Five subplots were established in each plot of the main experiment and management varied in mowing regime (one, two or four cuts per year) and NPK-fertiliser application (no fertiliser, 100 kg N ha^{-1} y^{-1} or 200 kg N ha^{-1} y^{-1}). Data was generally analysed in R using linear mixed effects models.

Results and discussion

Grassland productivity (harvested plant biomass) increased with plant species richness (Weisser *et al.,* 2017). Forage quality, quantified as organic matter, crude protein, usable raw protein, raw fat, neutral detergent fibre and metabolisable energy was independent of mean plant species richness (Scherer-Lorenzen *et al*., unpubl.). Effects of diversity on productivity (average difference between monocultures and 16-species mixtures: 449 g m^{-2} y^{-1}) were stronger than the intensification effect (average difference between lowest and highest intensification treatment: 315 g m^{-2} y^{-1}) in the management experiment (Weigelt *et al.,* 2009). Notably, positive effects of species richness on biomass production were also observed under intensive management over two years. In the long-run, intensification would likely reduce plant species richness. Thus, to harvest the diversity-related productivity advantage under high intensity would require a targeted management to maintain high plant species richness.

The Jena Experiment also investigated element cycling and water balance. To exemplify, soil carbon storage and water infiltration increased with increasing plant species richness (Weisser *et al.,* 2017). Higher plant species richness also increased organismic diversity and abundance of various organism groups, such as many animal taxa (Scherber *et al.,* 2010). Many consumers drive important ecosystem services, like pollination and pest control. Overall, about 45% of the investigated ecosystem processes were significantly affected by plant species richness (Allan *et al.,* 2013). Grasslands are expected to provide a combination of different functions and services. Combining many individual functions into a measure of ecosystem multifunctionality demonstrated that functioning as a whole increased with plant species richness (Meyer *et al.,* 2018). However, due to many functions showing trade-offs, ecosystem services relying on these functions could not be maximised together. Many processes, in particular belowground, took several years to respond to the manipulation of plant species richness, thus emphasising the special value of old, species-rich grasslands.

Our findings have implications for ecosystem management. Management to maximise a single ecosystem service will likely decrease provisioning of other ecosystem services, potentially even decreasing multifunctionality. Yet, it is possible to increase particular functions, such as biomass production via high diversity and simultaneously favour other functions such as increased water- or nutrient-use efficiency, resulting in reduced environmental impacts combined with potential economic benefits. In general, maintaining or increasing plant species in a grassland should likely increase some ecosystem functions. However, managing an ecosystem to maximise biodiversity will not necessarily maximise a particular subset of desired functions, and management for services will not necessarily protect biodiversity. We, thus, emphasise that ecosystem service provisioning cannot replace high biodiversity as the aim of conservation management.

Conclusion

The Jena Experiment shows that plant species richness has manifold effects on ecosystem functions in grasslands. Results indicate that diverse grasslands simultaneously support high productivity and additional ecosystem services. The future challenge will be to apply this knowledge to sustainable land use.

Acknowledgements

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Amazing Grazing: feed wedge and cutting window for grazing systems with high levels of supplementation

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Keywords: Amazing Grazing, feed wedge, cutting window, grass utilisation, feed supplementation

Introduction

In the Netherlands, many dairy systems are characterised by alternating use of grassland for grazing and fodder production and high levels of feed supplementation during the grazing season. A planning tool 'Grip op Gras' was developed to optimise on-farm fresh grass utilisation for these systems.

Materials and methods

'Grip op Gras' combines a feed wedge and cutting window and is based upon estimates of the DM yield of all on-farm grassland paddocks. The feed wedge in 'Grip op Gras', unlike existing feed wedges (Anonymous, 2009), varies the size of the grazing platform while target yield and target residual are fixed. So it can be decided which paddocks to use for grazing or fodder production, or to adjust the level of supplementation. Paddocks planned to be used for fodder production are moved from the feed wedge to the cutting window where information is provided to determine the best time for cutting. The default expected grass growth (kg DM ha^{-1} day^{-1}) can be adjusted by the user. 'Grip op Gras' was tested in practice by ten dairy farmers and advisors between April and July 2017. Half of them were familiar with estimating DM yield and the use of a feed wedge (group A), while the other half were not (group B). During the test period, participants provided weekly feedback.

Results and discussion

The use of data and tools in grassland management is not common practice in the Netherlands. Therefore, it was difficult to identify farmers and advisors willing to measure DM yield of all on-farm paddocks on a weekly basis and to use 'Grip op Gras'. Finally, only group A used 'Grip op Gras' weekly in their grassland management. The participants found that user-friendliness could be improved, especially in relation to input of data. The default expected grass growth was highly appreciated by the participants since it clarified the effect of time on grass availability for cutting and grazing. Utility and user-friendliness of 'Grip op Gras' was dependent on whether the user was familiar with the use of tools and data in grassland management; the more experienced had fewer problems than the less experienced.

Conclusion

The concept of the feed wedge and cutting window in 'Grip op Gras' was considered to be appropriate and satisfactory by the test panel of dairy farmers and advisors. A next step would be to improve the user-friendliness of the program.

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Optimising grass silage quality for green biorefineries

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Abstract

A pilot scale ensiling study was conducted to establish if liquid-solid separation of timothy and red clover silages could be improved by additive treatments. The treatments were controlled without additive, a formic acid based additive, a fibrolytic enzyme and a combination of formic acid and enzyme. Fibrolytic enzyme resulted in improved outcomes in this experiment. Furthermore, the results provided quantitative estimates of liquid yield and quality of liquid-solid separation of grass silages, useful for biorefinery pre-processing.

Keywords: additive, formic acid, enzyme, liquid-solid separation, timothy, red clover

Introduction

Grass provides a versatile raw material for green biorefineries and effectively converts solar radiation into chemical forms of energy. If preserved as silage, it can be used as feedstock all year round and existing technology is available for its cultivation, harvesting and ensiling (Wilkinson and Rinne, 2017). Ensiling converts water soluble carbohydrates into lactic acid and volatile fatty acids and protein is degraded to a varying extent. These changes may reduce the value of biomass entering a green biorefinery. However, ensiling may also serve as a pre-treatment for biorefining, thus indicating a potential trade-off. The objective of the current experiment was to evaluate how two forage species (timothy (*Phleum pratense*) vs red clover (*Trifolium pratense*)) and silage additive treatments (no additive, formic acid and fibrolytic enzymes) affect silage quality for biorefining. Yield from physical liquid-solid separation was used as an indicator as it is typically the first step of a green biorefinery.

Materials and methods

The experimental grass silages were produced at Jokioinen, Finland (60°48'N, 23°29'E) on 24 August 2016. The silages were second cut from pure stands of timothy and red clover. Both swards were harvested with a precision chopper without wilting and ensiled immediately in pilot scale silos, using three replicates per treatment. The treatments were controlled without additive (C), formic acid based additive (FA; AIV2 Plus, Eastman Chemical Company, Oulu, Finland at a rate of 5 l ton^{-1} fresh matter), a fibrolytic enzyme (E; Flashzyme Plus containing cellulase and hemicellulase activities, Roal Ltd., Rajamäki, Finland at a rate of 0.5 ml kg^{-1} DM) and a combination of FA and E (FA+E; first FA and then E from separate bottles). The silos were stored at room temperature with protection from light and opened after an ensiling period of 92 days. The liquid-solid separation was performed using two different laboratory scale methods: a double screw press (DS; Angel Juicer Ltd., Busan, South Korea) and a pneumatic press (PP; in-house built equipment, Luke, Jokioinen, Finland). The silage and respective juice fractions were analysed for chemical composition using routine methods, as described by Seppälä *et al.* (2016). Statistical analyses were performed using SAS GLM procedure separately for both species, and differences between treatment means were evaluated using the Tukey test.

Results and discussion

The chemical composition of the raw materials was not optimal because of exceptionally low crude protein (CP) concentration of timothy and DM concentration of red clover (Table 1). The plots were not fertilised after the first cut, which explains the low CP and ash concentrations of timothy. The humid weather around the second cut was reflected as low DM concentration of the ensiled materials. This resulted in poor quality of C silages, particularly in red clover (Table 2). The FA treatment effectively restricted fermentation and improved the fermentation quality and positive responses were also found with treatment E, particularly in red clover. The liquid yields were 0.661 and 0.420 (averaged over both species and all additive treatments) for DS and PP, respectively, showing a clear difference in the effectiveness of the liquid-solid separation methods (Table 2). The DM concentrations of the liquids were 68 and 49 g kg^{-1} for DS and PP, respectively, and lower than in our previous experiments (Rinne *et al.,* 2017), probably due to the low DM concentration of the original silages. The red clover liquid had 28% lower DM concentration but 44 and 39% higher ash and CP concentrations, respectively, than the timothy liquid, reflecting the silage composition. Although the results were not totally consistent, it seems that application of E could improve the amount of DM retained in the liquid fraction in mechanical separation of silage, which is consistent with Rinne *et al.* (2017).

Table 1. Description of the original silages.

	Timothy	Red clover
Dry matter (DM), g kg^{-1}	210	129
Buffering capacity, g lactic acid100 g^{-1} DM	4.4	11.2
In vitro organic matter digestibility	0.628	0.599
In DM, g kg^{-1}		
Ash	59	89
Crude protein	78	176
Water soluble carbohydrates	170	60
Neutral detergent fibre	592	485

Conclusion

The use of a fibrolytic enzyme and/or formic acid as a silage additive impacted (mostly marginally) on various characteristics likely to be relevant to biorefinery. Furthermore, the results provide quantitative estimates of liquid yield and quality of liquid-solid separation of grass silages for a biorefinery process.

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Table 2. Composition of the silages preserved using different additives[1] and subsequent liquid characteristics after mechanical separation.

	Timothy				SEM[2]	*P*-value[3]	Red clover				SEM	*P*-value
	C	FA	E	E+FA			C	FA	E	E+FA		
Dry matter (DM), g kg^{-1}	211	208	211	206	5.8	0.843	138	140	139	137	0.9	0.297
pH	3.77^{b}	3.93^{a}	3.78^{b}	3.85^{ab}	0.017	<0.001	5.49^{a}	4.07^{c}	4.36^{b}	3.95^{c}	0.027	<0.001
Ammonium N, g kg^{-1}N	60^{b}	84^{a}	63^{b}	82^{a}	3.4	0.002	113^{a}	95^{b}	94^{b}	83^{b}	3.0	0.001
Chemical composition, g kg^{-1} DM												
Ash	69	69	70	69	0.9	0.72	101^{a}	88^{b}	96^{a}	90^{b}	1.2	<0.001
Crude protein (CP)	84	93	89	92	2.8	0.175	191^{a}	181^{b}	192^{a}	182^{b}	1.8	0.005
Water soluble carbohydrates	33.3^{a}	17.6^{b}	30.1^{ab}	16.9^{b}	3.02	0.009	3.0^{c}	14.0^{b}	2.6^{c}	16.4^{a}	0.46	<0.001
Ethanol	49.8^{b}	61.4^{ab}	58.7^{ab}	71.6^{a}	4.15	0.036	39.8^{a}	12.0^{c}	12.7^{c}	17.6^{b}	0.81	<0.001
Formic acid	0.1^{b}	12.3^{a}	0.2^{b}	10.0^{a}	0.57	<0.001	4.5^{b}	33.7^{a}	1.1^{b}	31.7^{a}	1.48	<0.001
Lactic acid	105^{a}	53^{b}	100^{a}	60^{b}	4.4	<0.001	2^{b}	21^{ab}	56^{a}	21^{ab}	10.8	0.041
Acetic acid	19.5	20.0	17.3	20.4	1.55	0.515	70.1^{a}	17.4^{c}	60.8^{b}	17.5^{c}	0.51	<0.001
Propionic acid	0.5^{b}	1.0^{a}	0.5^{b}	1.0^{a}	0.016	<0.001	6.3^{b}	1.4^{c}	9.1^{a}	1^{c}	0.28	<0.001
Butyric acid	0	0	0	0	-	-	1.7	1.4	0.2	0	0.57	0.170
Liquid characteristics												
Proportion of fresh matter (DS[4])	0.623	0.610	0.637	0.643	0.0096	0.145	0.700	0.697	0.671	0.707	0.0081	0.061
Proportion of fresh matter (PP[5])	0.355	0.336	0.362	0.384	0.0107	0.071	0.479	0.488	0.467	0.492	0.0154	0.678
DM, g kg^{-1} (DS)	78.4	70.8	78.5	71.5	2.39	0.087	51.5^{a}	61.8^{b}	63.0^{bc}	64.8^{c}	0.63	<0.001
DM, g kg^{-1} (PP)	58.9	52.8	57.3	55.8	1.39	0.068	33.5^{a}	41.4^{b}	42.8^{b}	48.4^{c}	0.87	<0.001
DM retained in liquid (DS)	0.261^{ab}	0.232^{a}	0.292^{b}	0.259^{ab}	0.0119	0.045	0.279^{a}	0.330^{a}	0.322^{a}	0.362^{b}	0.0120	0.008
DM retained in liquid (DS)	0.100	0.092	0.112	0.122	0.0082	0.128	0.115^{a}	0.142^{ab}	0.130^{ab}	0.181^{b}	0.0133	0.041
Ash, g kg^{-1}DM (DS)	117	148	169	179	18.2	0.158	243	227	195	179	16.8	0.098
Ash, g kg^{-1}DM (PP)	147	169	150	155	10.1	0.441	282^{a}	175^{b}	254^{a}	221^{ab}	18.1	0.015
CP, g kg^{-1}DM (DS)	112	117	119	118	3.4	0.499	186^{a}	158^{b}	188^{a}	162^{b}	3.1	<0.001
CP, g kg^{-1}DM (PP)	84	85	87	84	2.8	0.785	121^{a}	98^{a}	110^{c}	99^{b}	1.1	<0.001

[1] C = control without additive, FA = formic acid based additive, E = fibrolytic enzyme, FA + E = FA and E combined.
[2] SEM = Standard error of the mean.
[3] Statisical significance between treatments. The treatment means were further separated using Tukey's test and means with different superscripts differ at $P < 0.05$.
[4] DS = Double screw juicer.
[5] PP = Pneumatic press.

Evaluation of ECMWF weather forecasts and their inclusion in an Irish grass growth model

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Abstract

Grass growth models (GGMs) have been developed with retrospective weather observations as inputs. However, forecasts have not been included. Daily forecasts from the European Centre for Medium-Range Weather Forecasts (ECMWF) predicting up to ten days in advance were verified at 25 Irish weather stations to test their viability for inclusion in GGMs. ECMWF forecasts of soil and air temperature variables generally performed well up to ten days. However, they often struggled to predict rainfall, particularly more than five days in advance. A bias correction approach using a regression model gave improvements in forecast accuracy for all temperature variables. None of the bias-correction techniques examined gave large improvements for rainfall forecasts. Predictions from the Moorepark St. Gilles (MoSt) GGM when using observations were compared to predictions using various weather forecasts. GGM predictions were similar when weather forecasts or observations were included. Overall, the work suggests that utilising weather forecasts, along with other relevant variables, in predicting future grass growth could be a valuable tool to farm management leading to better grassland usage, increased productivity and reduced costs.

Keywords: forecast verification, bias correction, grass growth modelling, air temperature, rainfall, soil temperature

Introduction

To meet targets to increase primary production and agri-food exports in Ireland in a sustainable manner, farming practices in Ireland must optimise the utilisation of available resources, in particular, grass. A grass growth model (GGM) predicting daily grass growth for the coming week to ten days would enhance the grassland management tools currently used by Irish farmers. GGMs using retrospective weather observations have been shown to describe on-farm grass growth accurately, including the Moorepark St. Gilles (MoSt) model (Ruelle *et al.,* 2016). When using a GGM to predict future grass growth, weather observations will not be available; forecasts must be used. Prior to the inclusion of weather forecasts, they should be verified for accuracy and bias corrected, as numerical weather prediction models often contain systematic biases. This paper details the results of the forecast verification and compares the predictions from the MoSt GGM using European Centre for Medium-Range Weather Forecasts (ECMWF) and bias corrected forecasts with those using weather observations and mean climatology forecasts.

Materials and methods

Daily weather forecasts and observations for rainfall, maximum, minimum, mean air temperature (2 m) and soil temperature at six depths (5, 10, 20, 30, 50 and 100 cm) at the 25 Met Éireann synoptic weather stations were obtained between 2007 and 2013. The ECMWF forecasts for lead times from day 1 to day 10 ('forecast periods') were used (McDonnell *et al.*, 2017). Mean climatological forecasts were also obtained for air temperatures and rainfall. Seven bias correction techniques were tested (Joliffe and Stephenson, 2011).

Predictions from the MoSt GGM at Teagasc Moorepark, Fermoy, Co. Cork, Ireland (52.17N; 8.27W) using weather observations and forecasts were compared. The MoSt GGM is an adaptation of the Jouven mechanistic model (Jouven *et al*., 2006), customised for local conditions. It incorporates sub-models describing the availability of N to the plants and the movement of water through soil (Ruelle *et al*., 2016). Inputs include management factors (e.g. N fertiliser application) and environmental factors (e.g. weather data). In the MoSt GGM predictions, the first yearly grazing occurred at grass height 9 cm and 8 cm thereafter. Post grazing sward heights were 3 and 3.5 cm for the first two yearly grazing events and 4 cm thereafter. Application rates of N were 40 kg ha^{-1} and 20 kg ha^{-1} on the day after the first grazing event and on day 65 of each year. Mean Systematic Bias (MSB) and Root Mean Squared Error (RMSE) were used to assess the accuracy of weather forecasts and GGM predictions.

Results and discussion

The ECMWF air temperature forecast RMSE values increased with forecast period. A bias correction technique using a regression model approach gave the greatest reductions in RMSE (compared to ECMWF forecasts) for almost all air and soil temperature variables, at every forecast period. Bias corrected forecasts improved upon the ECMWF air temperature forecasts, and may be more useful than mean climatology in a grass growth model up to one week in advance. It reduced the day 1 MSB values for maximum, minimum and mean temperature to 0.002 °C, 0.000 °C and 0.001 °C, respectively. The ECMWF soil temperature forecasts showed monthly differences in MSB, with the forecast consistently under-estimating the observed data in summer at all stations. The ECMWF soil temperature forecasts performed well; at greater depths, the forecasts were usually more accurate and the differences in RMSE values between forecast periods 1 and 10 were smaller (Figure 1a). The ECMWF soil temperature forecasts consistently under-predicted observations in summer. Bias correction gave large reductions in RMSE at all depths (Figure 1b).

Mean climatology rainfall forecasts gave lower daily RMSE values than day 7 ECMWF forecasts in all years at all stations. This suggests that after seven days, mean climatology values would be more useful in a grass growth model than ECMWF rainfall forecasts. The MSB of day 5 forecasts for all observations between 40 and 50 mm was -31.3 mm, indicating that high rainfall events were usually under-predicted

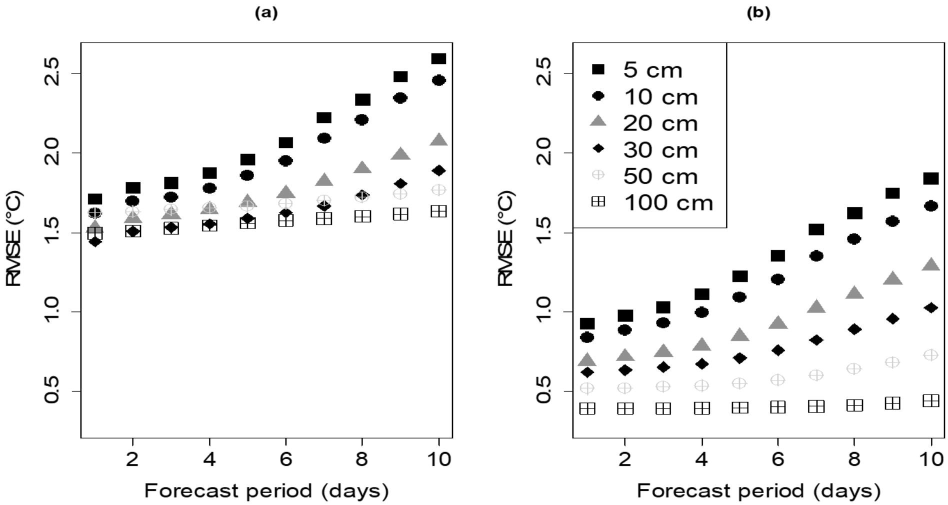

Figure 1. RMSE (°C) of observations and (a) ECMWF and (b) bias corrected soil temperature forecasts across all stations for forecast periods 1 to 10.

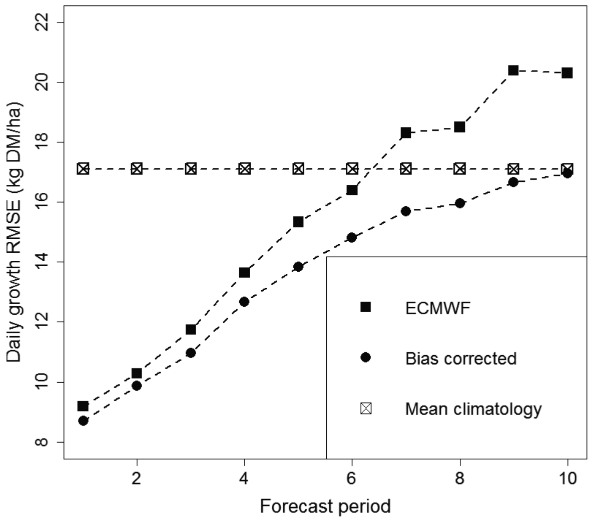

Figure 2. RMSE (°C) values comparing daily grass growth predictions from the MoSt GGM using observations to daily grass growth predictions from the MoSt GGM using (1) ECMWF, (2) bias corrected and (3) mean climatology forecasts.

at long lead times. The ECMWF rainfall forecasts were not improved significantly by any of the bias corrections. Inaccurate forecasts of high rainfall events could negatively impact on GGM prediction accuracy (McDonnell *et al.,* 2017).

Daily grass growth predictions from the MoSt GGM using ECMWF and bias corrected forecasts all gave similar RMSE values when compared with predictions using observed values for forecast periods of less than four days (Figure 2). However, at longer lead times, bias corrected predictions performed better. Day 10 bias corrected forecasts were almost matched by mean climatology, while ECMWF forecasts were out-performed by climatology after a week (Figure 2). Predictions from the MoSt GGM using forecasts gave similar weekly and monthly grass growth trends to those using observations.

Conclusion

The ECMWF air and soil temperature forecasts were improved by bias corrections, but rainfall forecasts were not. The best bias corrected weather forecasts yielded grass growth predictions from the MoSt GGM better than climatology forecasts up to ten days in advance.

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Use of PLS Regression as a tool for rapid estimation of herbage intake in grazing cows

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Abstract

It is important to rapidly estimate the daily intake of nutrients for grazing animals at farm level. This preliminary study aims to evaluate the use of a multivariate statistical analysis for rapid prediction of the herbage DM intake (HDMI, kg DM cow^{-1} day^{-1}) of cows grazing a Mediterranean pasture. A Partial Least Square Regression (PLSR) analysis was applied to a dataset consisting of body weight, metabolic weight and nitrogen content in the faeces of 19 mature Sarda cows and chemical composition of herbage selected by the animals. These data were obtained by following the cows at pasture and mimicking their feeding behaviour. The PLSR enables construction of predictive models when the factors are numerous and highly collinear. For model evaluation, estimates based on n-alkane methods were used as actual HDMI values. The means ± SD of actual and predicted HDMI, R^2 values and root mean square error of prediction (RMSEP) were 11.9 ± 3.6, 12.2 ± 2.6, 0.61 and 2.17 ($P < 0.0001$). These preliminary results show that the method has potential for local use at farm scale. Before a practical application, further insights are required which may be achieved by increasing the number of samples and the range of values of predictive variables used.

Keywords: beef cattle, pasture, modelling, multivariate statistics

Introduction

The amount of feed consumed (DM intake, DMI) is the most important factor that influences the animal's productivity and efficiency. In grazing systems, voluntary intake should be estimated, together with *in vivo* digestibility, in order to improve pasture management and grazing ruminant performance. The feed intake in ruminants is regulated by multiple mechanisms related to dietary and animal factors (Ingvartsen, 1994; Decruyenaere *et al.*, 2009) and interactions between these two factors further complicate predictions. Moreover, the methods of DMI estimation of grazing animals are often expensive and time-consuming (Ungar, 1996). For these reasons, precise models able to deliver information at farm level and in 'real-time' with minimal intervention have received particular attention. According to Ingvartsen (1994), feed intake models should include prediction equations based on feed characteristics and animal factors. This study represents a first attempt to predict the herbage DM intake (HDMI, kg DM head^{-1} day^{-1}) of cows grazing a Mediterranean pasture, using a multivariate statistical analysis of variables readily determinable.

Materials and methods

Data were collected from two feeding experiments carried out in May 2015 and March 2017 (Acciaro *et al.*, 2017) with, respectively, ten and nine mature Sarda suckling cows (body weight BW 425 ± 51, means ± s.d.). The herbage DM intake (HDMI) of animals was assessed by the n-alkanes method (Mayes *et al.*, 1986). The cows grazed 24 h day^{-1} without supplementation. During the experiments, faecal (FS) and hand-plucked herbage samples (HS) were collected. Herbage sampling was performed by mimicking the feeding behaviour of the cattle (Berry *et al.*, 2002) to ensure that the samples represented the herbage consumed by the animals. Faecal nitrogen content FS was determined by Kjeldahl method. The DM content, ash, ether extract (EE) and CP (AOAC, 1990), neutral detergent fibre and acid detergent fibre on an ash-free basis (NDFom and ADFom), acid detergent lignin (ADL, van Soest *et al.*, 1991) were determined in HS. Using Partial Least Square Regression (PLSR) procedure, relationships were identified between HDMI as dependent variable, and BW, metabolic weight (MW) faecal nitrogen and diet chemical composition (DM, CP, NDFom, ADFom, ADL, EE, ash) as independent variables. The HDMI values estimated by the n-alkanes technique was used in the PLSR procedure as reference values under grazing (Decruyenaere *et al*., 2009). The use of PLSR derives from its ability to handle multivariate regression models with high collinearity among predictors and to make prediction more efficient compared to ordinary multivariate regression or principal component regression (Dimauro *et al*., 2011). The root mean square error of prediction (RMSEP) was used to assess the prediction ability of PLSR. The PLSR was carried out with plsr function (library pls) of R (2016). Finally, the precision and accuracy of the model were assessed implementing the Model Evaluation System (MES, release 3.1.16, Tedeschi, 2006). The model evaluation was based on Anderson-Darling test, Dent and Blackie test and R^2.

Results and discussion

The mean and range values of HDMI, nitrogen content in the faeces and chemical composition of HS are shown in Table 1.

Within the boundary of the above ranges, despite the limited number of data used in the analysis, PLSR procedure was able to provide a HDMI estimate (12.2 ± 2.6 kg DM cow^{-1} day^{-1}), close to the actual value (11.9 ± 3.6 kg DM cow^{-1} day^{-1}), with a RMSEP of 2.17. Among the MES results (Table 2), Anderson-Darling test (p-value = 0.08) showed that residuals of regression were normally distributed, whereas Dent and Blackie test (not significant, p-value = 0.86) and $R^2 = 0.62$ indicated that the prediction was accurate with an acceptable degree of precision.

Table 1. Body weight of beef cows, herbage DM intake, faecal nitrogen content and herbage chemical composition used in PLSR analysis.

	Means ± s.d.	Range of values
Body weight (kg)	425 ± 51	365 - 570
Herbage dry matter intake (kg cow^{-1} day^{-1})	11.9 ± 3.6	7.2 - 18.8
Faecal Nitrogen content (%DM)	24 ± 0.3	1.9 - 2.9
Herbage DM content (%)	20.9 ± 2.2	18.8 - 23.2
Herbage CP content (%DM)	19.5 ± 3.9	15.8 - 23.6
Herbage NDFom content (%DM)	44.4 ± 9.9	34.3 - 53.6
Herbage ADFom content (%DM)	24.9 ± 5.0	19.8 - 29.7
Herbage ADL content (%DM)	2.7 ± 0.1	2.6 - 2.8
Herbage EE content (%DM)	3.6 ± 0.9	2.9 - 4.9
Herbage ash content (%DM)	11.7 ± 0.4	11.4 - 12.1

Table 2. Evaluation of model sourced from PLSR implemented to predict herbage DM intake (HDMI).

Actual herbage dry matter intake (kg cow^{-1}day^{-1})	11.9 ± 3.6
Predicted herbage dry matter intake (kg cow^{-1}day^{-1})	12.2 ± 2.6
Anderson Darling test	$P = 0.08$
R^2	0.62
Dent and Blackie test	$P = 0.83$

This static and empirical model represents an initial attempt to predict intake of suckling cows grazing a Mediterranean pasture. A more complete database is needed to increase the robustness of the model and to widen its application. To this end, further experimental data will allow an increase in the range of values of predictive variables used in the model. It will be equally important to widen the number of predictive variables, including intake-driving variables such as those related to pasture characteristics or environmental conditions.

Conclusion

Despite the difficulty to estimate herbage intake in grazing situations and to develop a model able to make an accurate and precise HDMI estimate, the PLSR procedure seems to be a promising tool to develop robust prediction of this variable, a prerequisite for optimising beef production at farm level.

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Measuring grass growth using satellite technologies

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Keywords: remote sensing, satellite, spectral reflectance, grass biomass

Introduction

Current technologies for monitoring grass yield are either labour intensive or not well developed. There is potential for developing satellite remote sensing technology to provide cheap methods of remotely sensing grass yield. The recent increase in capabilities of both Synthetic Aperture Radar (SAR) and optical systems, particularly those provided with free open access under the EU Copernicus programme will enable crops to be sensed regularly and with less cost. If this technology can be developed to enable grass yield to be estimated at a sub-field scale (tens of metres) using automated and cost effective approaches, then this will help farmers increase production efficiency by managing inputs and livestock more precisely. This paper tests the hypothesis that satellite data can be used to estimate grass growth.

Materials and methods

Rising plate meter measurements of grass biomass (kg dry matter ha^{-1}) were collected for over 1000 field × date combinations on 16 farms in England and Wales during 2016 and 2017. All available satellite imagery from within the sampling period was downloaded for Landsat 8 (optical data), Sentinel-2 (optical data) and Sentinel-1 (SAR data). Following processing, the optical satellite data were used to calculate several spectral reflectance indices, e.g. Normalised Difference Vegetation Index (NDVI), Wide Dynamic Range Vegetation Index (WDRVI), and the SAR satellite data were converted to backscatter coefficients.

Results and discussion

Over 100 of the ground reference field measurements coincided (within three days) with an optical satellite image and 183 field measurements coincided with an SAR satellite image. Strong associations were found across all fields relating several optical spectral reflectance indices with grass biomass; correlation coefficients of up to 0.72 were obtained. Data from Sentinel-2 has a resolution of 10 m which means that this technology can accurately describe intra-field variation in grass biomass. The SAR was less successful at measuring grass biomass but has been used to monitor hay cutting and grazing events. We aim to combine satellite information with grass growth models to develop systems for efficiently monitoring and predicting grass biomass.

Conclusion

Optical information collected by satellites can be used to estimate grass biomass. These biomass estimations and modelling approaches will be combined in location specific applications to allow farmers to access grass growth information at field and sub-field levels.

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Optimisation of artificial neural networks to predict digestibility of perennial ryegrass using near infrared reflectance spectroscopy

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Abstract

Near infrared reflectance spectroscopy (NIRS) relates spectral data to reference laboratory data using predictive calibration models. Artificial neural networks (ANN) are a form of machine learning and have advantages over multivariate linear regression models that are commonly used for quantitative forage analysis. There is uncertainty in how to select the optimal number of primary and secondary hidden nodes to maximise the predictive accuracy of an ANN. The current study evaluated modifying the number of input variables, primary and secondary hidden nodes to optimise the accuracy of ANNs to predict the digestibility of perennial ryegrass (*Lolium perenne* L.). As a general trend, increasing the number of primary and secondary hidden nodes increased accuracy of the calibration set, however, there was an associated decrease in the accuracy of the validation set indicating a tendency to over-fit the ANN with increased complexity. Whilst optimising an ANN, caution must be applied to prevent over-fitting of the model specific to the calibration set and that results can be applied to samples outside of the calibration set.

Keywords: near infrared reflectance spectroscopy, perennial ryegrass, digestibility, artificial neural network, machine learning

Introduction

Near infrared reflectance spectroscopy (NIRS) is a secondary technique that utilises predictive calibration models to estimate reference laboratory values based on the near infrared absorbance spectrum. For quantitative forage analysis, the most commonly used technique in the literature to form NIRS calibration models is multivariate linear regression (MLR) modelling (Burns *et al.*, 2013). Machine learning algorithms, such as artificial neural networks (ANN) are an alternative to MLR calibration models and offer several advantages; they can model non-linear relationships and have the ability to account for interactions between all predictor variables (Blanco *et al.*, 1999). Despite this, the use of ANN in the literature for quantitative forage analysis is limited, although it is more common in other quantitative analysis in other research areas (Perez-Marin *et al.*, 2007). The potential lack of use may be due to the lack of interpretability; the significant expertise required to develop the ANN and limited established guidance on how to select a number of factors to optimise the predictive accuracy of the model. The aim of this study was to optimise the predictive accuracy of a back-propagated ANN to predict the digestibility of perennial ryegrass, by modifying the number of primary and secondary hidden nodes.

Materials and methods

As part of the forage grass breeding programme at Loughgall, Co. Armagh, perennial ryegrass plots (9 m^2) were sown between 2011 - 2015 and harvested on five to nine occasions throughout the growing season following the UK national list protocol. A total of 968 samples were randomly selected from harvested plots within the breeding programme for further analysis, whereby, a *c.* 300 g sub-sample was collected and dried at 80 °C for 18 h and subsequently milled through a FOSS CT 193 Cyclotec™ sample mill. The absorbance (log 1/R) spectrum of each sample was measured between 1,108 and 2,500 nm using a FOSS NIRsystems 2500 (ISIScan v. 2.00), and subsequently analysed for *in vitro* dry matter digestibility using the reference laboratory techniques. Raw spectra files were exported as csv files and all subsequent analysis was carried out using R (v 3.2.2). A principle component analysis was applied to the spectral data and the first 20 principle components were stored to be used as input variables. The sample set was randomly assigned to a calibration (n = 726) and a validation set (n = 242). A series of artificial neural network models were developed using the 'neuralnet' package (Fritsch and Guenther, 2016), using a back-propagation method with a threshold of 0.01 for the partial derivatives of the error function as stopping criteria. The first 14,16 and 18 PC's were selected as input variables to the ANN and the number of primary hidden nodes selected as either 8 or 10 and secondary hidden nodes as either 4 or 6. For each combination of input parameter, primary and secondary hidden; the coefficient of determination (R^2) and standard error of calibration (S.E.C.) were calculated. For the validation set, each ANN was used to predict the values in the validation set and to calculate the coefficient of determination (R^2) comparing predicted and references values.

Results and discussion

All ANNs developed in the current study could accurately predict the *in vitro* DM digestibility of perennial ryegrass (Table 1; R^2 0.845 - 0.896). Previous studies have reported NIRS calibration models, using MLR models to predict digestibility to be similar accuracy (R^2 0.83 - 0.96; Burns *et al.,* 2013). Modifying the number of input variables, primary and secondary hidden nodes provided scope to optimise the model for predictive accuracy. A general trend was observed, whereby increasing the number of input variables resulted in increased accuracy of the calibration model. However, there was decrease in accuracy when comparing the S.E.C. and S.E.P, suggesting each ANN is over-fitting and that the results are specific to the calibration set. With increasing complexity of the ANN, there is a trend of increased over-fitting, suggesting care must be taken when optimising an ANN to ensure the results are robust and not specific to the calibration set. Due to the complexity of an ANN, a large number of calibration samples are required to accurately determine the optimal relationship between nodes (Perez-Marin *et al.*, 2009). The current study had a relatively low number of samples in the calibration set (n = 726) and

Table 1. Calibration statistics of Artificial Neural Networks (ANN) modifying the number of input variables, primary and secondary hidden nodes.[1]

Input	Hidden Nodes		ANN		Validation	
Number of PCs	Primary	Secondary	R^2	S.E.C.	R^2	S.E.P.
14	8	4	0.845	18.03	0.750	24.32
14	12	4	0.865	16.84	0.708	26.65
14	8	6	0.898	14.61	0.626	32.16
14	12	6	0.870	16.50	0.719	26.11
16	8	4	0.860	17.14	0.723	25.86
16	12	4	0.881	15.80	0.666	29.15
16	8	6	0.879	15.90	0.704	26.58
16	12	6	0.861	17.10	0.724	25.76
18	8	4	0.866	16.74	0.757	23.85
18	12	4	0.848	17.87	0.735	25.15
18	8	6	0.896	14.76	0.714	26.21
18	12	6	0.895	14.84	0.733	25.09

[1] PC – Principal Components; S.E.C – standard error of calibration. S.E.P. – standard error of prediction.

although there is no absolute minimum value number of samples required for machine learning, a large calibration set is recommended to accurately model the large number of relationships between nodes.

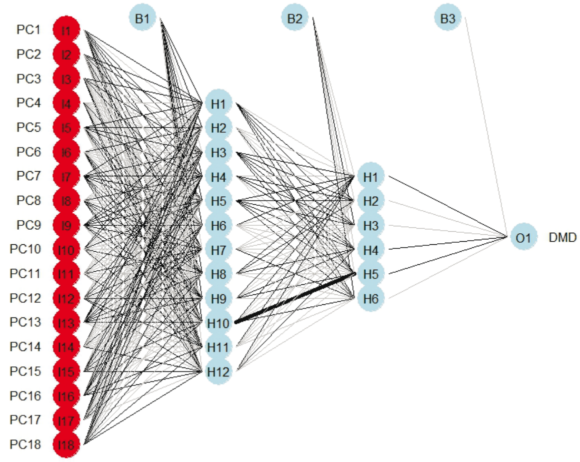

Figure 1. Artificial Neural Network with 80 input variables, 12 primary and 6 secondary hidden nodes to predict *in vitro* DMD. Line thickness indicates magnitude of weighting; black and grey lines indicate positive and negative values. B nodes represent a bias adjustment.

Conclusion

The use of ANNs to predict the digestibility of perennial ryegrass based on NIR absorbance data was of similar accuracy to the models developed using MLR techniques. The current study provided evidence of the ability to optimise the predictive accuracy of ANNs through modifying the number of input variables, primary and secondary hidden nodes. However, this study also reported evidence of increasing over-fitting of the model with increasing complexity of the ANN. As the size of NIRS calibration sets are becoming increasingly larger, ANN provide an opportunity to account for non-linear bias and potentially improve the accuracy of results.

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Evaluation of near infrared reflectance spectroscopy calibration selection techniques

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Abstract

Near infrared reflectance spectroscopy (NIRS) calibration models relate spectral data to reference laboratory data based on a set of calibration samples. Obtaining this reference data is expensive and time consuming and calibration selection techniques offer a method to reduce the number of calibration samples whilst maintaining the desired accuracy of the calibration models. This study compared the 'Select' calibration selection technique with selecting calibration samples at random for four grass quality traits. For buffering capacity, as the size of calibration set reduced, there was a similar decrease in accuracy and robustness of calibration with both the 'Select' and random techniques. However, when assessing *in vitro* DM digestibility, when using the 'Select' technique, the coefficient of determination increased as the calibration set was reduced. This was associated with a decrease in the robustness of the calibration models. Use of the 'Select' algorithm did not result in better performance compared to the simple random sampling technique. This may have been a consequence of the lowest calibration sub-set still being adequate to represent the variation present, as indicated by the acceptable accuracy and robustness achieved at all calibration sample sizes.

Keywords: near infrared reflectance spectroscopy, ryegrass, nutritive quality, calibration selection strategy

Introduction

Near infrared reflectance spectroscopy (NIRS) is a routine method of assessing herbage nutritive quality in grass evaluation and breeding programmes (Burns *et al.,* 2013). The NIRS utilises predictive calibration models to relate spectral data to reference laboratory data based on a set of calibration samples. Obtaining the reference laboratory data is expensive and time consuming, and calibration selection techniques offer a method to reduce the size of the calibration set whilst maintaining the desired accuracy and robustness of calibration. Shetty *et al*. (2012) reported that an 80% calibration set size retained an acceptable level of accuracy when using calibration selection techniques for the prediction of nitrogen in grasses. However, NIRS calibration models for nitrogen are frequently cited as the most accurate amongst nutritive quality traits (Burns *et al.,* 2013) and it is unclear if similar reductions could be achieved whilst maintaining accuracy for other quality traits. Shetty *et al.* (2012) concluded that to maximise the accuracy of calibration models per unit effort, the methodology of sample selection is more important than the number of samples in the calibration set. The aim of this study was to compare the 'Select' calibration selection technique (Shenk and Westerhaus, 1991) with a random selection of calibration samples to develop NIRS calibration models for predicting buffering capacity (BC) and *in vitro* DM digestibility (DMD).

Materials and methods

Varietal monocultures were sown in randomised complete block design (n = 4) trials at Backweston, Co. Kildare, Ireland between 2002 - 2008. The calibration set of Burns *et al.* (2013) was utilised which consisted of 2,076 ryegrass samples that encompassed the range in climatic conditions, ryegrass species and varieties, developmental stage, ploidy, genotype and age of sward that occur in the Recommended List trials operated by Department of Agriculture Fisheries and the Marine in Ireland. For each sample an absorbance spectrum (log 1/reflectance) was obtained between 800 - 2,500 nm using a FOSS NIR systems XDS. Spectral pre-treatments and respective reference laboratory analysis for BC and DMD was carried out as per Burns *et al.* (2013). Two calibration selection techniques were applied to select calibration subsets, each with five levels of selection criteria applied:

- The 'Select' algorithm of Shenk and Westerhaus (1991) was applied using the WinIS software (FOSS; v 4.0). The 'Select' algorithm is an iterative algorithm, whereby, an initial sample is selected as the sample that has the most neighbours based on a user defined Malanobis distance. The neighbours of this sample are removed and the next sample is selected as the sample that has the most neighbours based on a user defined Malanobis distance. This is repeated until only samples with no neighbours remain. Neighbourhood H (NH) values of 0.2, 0.4, 0.6, 0.8 and 1.0 were applied to select calibrations sub-sets from within the full calibration.
- Random - Full (100%), 60, 20, 10 and 5% of samples were randomly selected from the full calibration set.

Predictive regression models and cross-validations were carried out for each calibration sub-set as per Burns *et al.* (2013).

Results and discussion

For a given sample size, the calibration models for *in vitro* DMD had a lower R^2 and larger SEP than BC. The calibration sub-sets from the 'Select' technique resulted in a 34, 74, 85, 90 and 96% reduction in calibration set size using the NH criteria of 0.2, 0.4, 0.6, 0.8 and 1.0 (Table 1). The random selection of 20% calibration samples resulted in a negligible change in the coefficient of determination for BC and a 2% decrease for DMD. Using the 'Select' technique, for BC a decreased calibration sub-set size tended to slightly decrease the R^2 of the calibration model, with the smallest calibration set (NH = 1.0) resulting in an 8% reduction for BC. In contrast, for DMD there was an increase in R^2 for the smallest calibration sub-sets, however, the R^2 of the cross-validation model for DMD decreased as the calibration set size decreased (not reported), indicating a less robust model whilst analysing samples outside the calibration set. For all selection techniques and traits, as the calibration size decreased there was an associated decrease in the robustness of these models as indicated by the increased standard error of cross-validation (SECV; Table 1). Shetty *et al.* (2012) reported that calibration selection based on spectral techniques resulted in a lower decrease in accuracy in comparison to random selection for the prediction of CP in grasses. Comparison of the 'Select' and random calibrations with similar sample numbers showed a similar or slightly lower SECV with the random method. However, the current study had a calibration set almost 20 times the size of Shetty *et al.* (2012) (n = 2,076 vs 118). Therefore, the number of samples within the smallest calibration sub-set in the current study may adequately describe the relationship between the near infrared absorbance and quality trait. For BC, selection based on spectral techniques resulted in a larger standard error of calibration for a similar calibration size (24.4 vs 20.4). A potential explanation is that selection using spectral data will select proportionately more samples at the edge of principle component space in comparison to random selection. These samples are, therefore, at the edge of the population and so linear regression models for BC may be limiting. In contrast, the DMD model had a higher coefficient of determination for calibration models, with samples selected based on spectral data. The samples at the edge of the population contained the highest and lowest DMD values and were thus extensions of the population. The use of calibration selection techniques to select representative calibration sub-sets, therefore, is a potential mechanism to reduce the number of reference laboratory samples, conferring substantial cost and time savings. These savings must be considered in the context of a small decrease in the accuracy and robustness of NIRS calibration models and a trade-off for the requirements of the end user.

Table 1. NIRS calibration statistics for models developed using calibration subsets selected using the 'Select' technique or simple random sampling.[1]

'Select' technique						Simple random sampling				
NH	n	BC		*In vitro* DMD		n	BC		*In vitro* DMD	
		SEC	R^2	SEC	R^2		SEC	R^2	SEC	R^2
0.2	759	21.6	0.94	16.9	0.86	2,076	20.3	0.95	16	0.86
0.4	311	22.4	0.93	18.6	0.84	1,246	21.4	0.95	17.6	0.84
0.6	191	29.6	0.89	20.1	0.83	415	20.6	0.96	17.5	0.85
0.8	131	29.1	0.9	21	0.84	208	22.2	0.95	16.9	0.88
1.0	86	30.9	0.88	16.9	0.9	104	23.6	0.95	15.5	0.89

[1] BC - Buffering capacity (mEq kg^{-1} DM); *in vitro* DMD – *in vitro* DM digestibility (g kg^{-1}); NH – Neighbourhood H; SE^{C} – Standard Error of Calibration.

Conclusion

Ultimately, the end user must choose the desired balance of accuracy and robustness of NIRS calibration models that best suits their needs. If the end user would like to optimise the allocation of resources, selecting calibration for reference analysis using the 'Select' technique results in calibration models of similar or better accuracy compared to simple random sampling. Therefore the 'Select' technique provides a methodology to reduce the number of samples requiring reference laboratory analysis, whilst matching the requirements of the end user.

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A new approach to N fertiliser advice on grassland in the Netherlands

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Abstract

Advice on the nitrogen (N) fertilisation of grassland is usually based on the N supply of the soil (SNS). Generally, a higher SNS results in advice for lower N fertilisation rate. Recent research showed that the recommended N fertiliser rate can deviate by more than 60 kg $ha^{-} y^{-1}$ from the optimum. Historic and recent grassland field trial data are, therefore, re-analysed to improve the accuracy of optimum fertiliser rates. Since 1950, over 250 trials were carried out on 140 different locations, resulting in a database with about 10,000 records. The main soil types were sand (46%), clay (21%), river clay (4%) and peat (28%). Analysis showed that the SNS increased over time and that the apparent nitrogen recovery (ANR) was constant over N doses varying between 0-350 kg $ha^{-1} y^{-1}$. However ANR varied considerably between sites and years. We used machine learning algorithms (random forest models) to estimate the ANR in response to soil, weather and management. Initial results showed that it was possible to accurately distinguish fields with ANR.

Keywords: soil N delivery, ANR, N fertiliser, random forest

Introduction

In the Dutch advisory system, the soil N supply (SNS) is based on the quantity of total N in the top 10 cm of a soil profile. It is derived from a statistical relationship between the annual N-uptake of unfertilised plots and the total N content of soils based on long-term series of field trials (Hassink, 1995, 1996) and some more recent field trials. The SNS, therefore, gives an indirect estimation of the real N-mineralisation in soil. Nowadays, it is important to use fertilisers (and manures) efficiently to prevent negative environmental effects while maximising N uptake. Thus, the question if SNS is sufficiently accurate enough to meet future targets for efficient fertilisation is important. A recent desk study (Ros and Van Eekeren, 2016) showed that the annual recommended N fertilisation rate can deviate by more than 60 kg N $ha^{-1} y^{-1}$ from the optimum according to the Dutch N recommendation system (Anonymous, 2017). We have, therefore, investigated the background of this deviation and how SNS, apparent N recovery (ANR) and N fertiliser rate are related. A first analysis of field trial data from 1950 - 2015 (unpublished results) shows large variation in the ANR. The ANR varied considerably between sites, years and soil types with small dependency on N fertiliser rate. Furthermore, ANR decreased with SNS, with a strong soil type effect.

To optimise the fertiliser efficiency, it is important to be able to predict which fields have a high ANR while accounting for actual fertiliser management, soil properties and weather conditions. If we are able to make such a prediction, the farmer can use his restricted amount of nitrogen (by law) more efficiently, resulting in higher yields and more protein in the herbage. To predict which fields have the highest ANR, we analysed available grassland field trial data in the Netherlands using an innovative data driven approach (machine learning).

Materials and methods

Almost all available Dutch field trial data (> 250) over the last decades were collected, including soil properties, grass properties (ryegrass, age), groundwater table (Gt), weather data (rainfall, temperature, radiation during growth and close to fertilisation dates), and nutrient management (timing, dose and fertiliser type). Focusing on N fertiliser trials, 5,224 annual experiments have been selected with N doses varying between 30 and 900 kg N ha^{-1} (excluding the zero fertilised plots). From this dataset a subset (5,224 records) with seasonal yields and fertiliser rates below 1000 kg N ha^{-1} y^{-1} were selected to evaluate the factors controlling ANR. The resulting database subset contained field trial data from 1941, 1942 and the period 1959 up to 2014. The main soil types included sand (40%), clay (34%), river clay (3%) and peat (22%). About 23% of the data had N fertiliser levels above 400 kg ha^{-1} yr^{-1}. There were 342 location by year combinations and 3,450 location by year by treatment combinations.

We studied the possibility of predicting ANR of individual fields using random forest (RF) algorithms; RFs are an ensemble learning method for classification and regression. It operates by constructing a multitude of decision trees at training time and outputting the class, that is the mode of the classes (classification) or mean prediction (regression) of the individual trees (Witten and Frank, 2005). The advantage of RF over decision trees is that it prevents overfitting to the training set.

Results

The effects of the most important soil, weather and management factors on the ANR (based on all trial data before 1998, about 90% of the data; the calibration set) are shown in Figure 1. The Gt, fertiliser type, DM yield (DMY), and fertiliser rate were the most dominant factors controlling ANR. Validating the model on all field experiments after 1998 showed that the ANR can be predicted quite satisfactorily (R^2 = 0.76). Restricting the prediction model to the top 10 most relevant factors did not strongly reduce model performance (R^2 = 0.74). In-depth analysis of the forest floor (analysing the cross validated feature contribution

of individual factors) confirmed the impact of Gt, DMY, precipitation on fertiliser date and the number of high rainfall events. ANR increased almost linearly with DMY, whereas N rate showed almost no effect within the range of common N fertilisation doses. Low Gt generally resulted in lower ANR, with a maximum effect of almost 10%. At low N fertilisation doses (< 100 kg ha^{-1}), the ANR was slightly (max

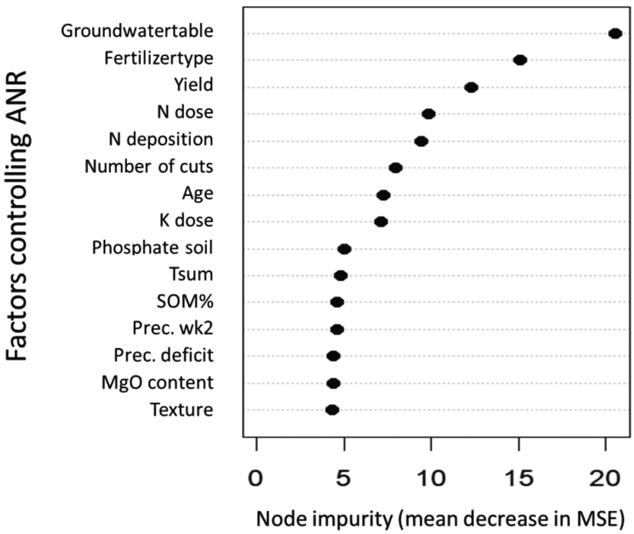

Figure 1. The 15 most important factors of the RF model controlling ANR (impurity is measured by residual sum of squares; node impurity refers to total decrease in MSE on the variable, averaged over all trees).

5%) higher. The Gt and DMY had the strongest effect. Using this reduced training set for the validation set (trials after 1998) resulted in R^2 of 75%. For practical implementation in fertiliser recommendation systems, we distinguish five possible soil classes with different N fertiliser recoveries (Table 1). Validating the trained RF model on the field experiments from last decade (after 1998) allowed us to predict the ANR class correctly for 67% of the included field experiments. In approximately 30%, the ANR was over or underestimated by 20%. This approach is thus very promising and can, in principle, be used as selection criteria to distribute N fertiliser over fields.

Table 1. Predicted versus actual ANR for the field trial data 1998 - 2014 (10% of the subset).

Predicted ANR	Actual ANR				
	< 0.2	0.2 - 0.4	0.4 - 0.6	0.6 - 0.8	> 0.8
> 0.8	0	0	0	7.2	7.8
0.6 - 0.8	0	0	4.2	23.4	0.6
0.4 - 0.6	0	1.2	31.7	7.2	0.6
0.2 - 0.4	0	3.6	6.6	0	0
< 0.2	0.6	4.2	0	1.2	0

We tested this approach also on individual cuts. The results were improved and weather parameters became more dominant. This, in principle, gives opportunities for more weather related fertiliser management, but it needs further investigation.

Before implementing this concept, further testing is needed, including evaluation in practice, to check if this approach is workable for farmers. In addition, the question arises if ANR and SNS can be used at the same time, since SNS indicates an optimum of N fertiliser above the natural soil delivery, and ANR predicts where N is most effective.

Conclusion

Prediction of the ANR for classification of individual fields has potential. Based on random forest analysis of a large historical database of field trials results, including soil and weather data, we were able to predict the ANR for 67% of the annual field trials correctly. In principle, it is now possible to allocate N fertiliser to fields with the highest ANR.

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Ambient conditions and production system influence oxygen isotope composition of water in milk from cows (*Bos taurus*)

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Abstract

There are increasing concerns by consumers with respect to agricultural product traceability and authenticity. Oxygen isotope composition ($\delta^{18}O$) has been used in this context and is based on the relationship between $\delta^{18}O$ of animal products and that of annual precipitation. However, in dairy products this relationship is affected by the seasonality of $\delta^{18}O$ in milk water which, in turn, depends on the production system. Milk samples (n = 608) were collected from 28 farms in southern Germany throughout a year to investigate the influences of ambient conditions, drinking water sources and production system on the seasonal variation of $\delta^{18}O$ in milk water. The mechanistic Munich-Kohn model reflecting these influences on body water turnover successfully predicted the seasonal and farm-specific variation of $\delta^{18}O$ in milk water. Due to its mechanistic character, the model is a versatile tool for analysing the influences of various production parameters even beyond the range of the 28 farms. However, ambient conditions exert a strong influence and thus can modify and dampen the signal of the production system on $\delta^{18}O$ in milk water.

Keywords: animal environment, feeding, silage, grass, animal keeping

Introduction

With the frequent global exchange of animal products, identifying authenticity and geographical origin of animal products has become crucial among consumers and authorities (Camin *et al*., 2008; Chesson *et al*., 2010). Analysis of stable isotopes of bioelements has been proven to be well suited for this purpose (Rossmann *et al*., 2000). However, the use of oxygen isotopes ($\delta^{18}O$) in animal products is challenging. The geographic tracing by $\delta^{18}O$ is mainly based on the relationship between $\delta^{18}O$ of animal products and that of annual precipitation and the well-known global pattern of precipitation. The seasonal variation of $\delta^{18}O$, deriving from both ambient conditions and production systems may potentially distort the geographic information. It is crucial to build a mechanistic model to explain the seasonality of $\delta^{18}O$ in animals and test the efficiency of the model. The Munich-Kohn model (or MK model), extended from the Kohn model (Kohn, 1996), has been validated by estimating $\delta^{18}O$ in tail hair of one cow subject to two feeding strategies (Chen *et al*., 2017a). Here, this model will be further examined with more farms, feeding strategies and for a relevant cattle product, namely milk.

Materials and methods

A total of 28 farms in southern Germany with different cow feeding strategies grouped as (1) grass fed on pasture, (2) stall feeding of cut grass, and (3) feeding no fresh grass were investigated. Well mixed tank milk of these farms was sampled biweekly over one year (n = 608; for details see Chen *et al*., 2017b). The $\delta^{18}O$ in milk water was measured by an IsoPrime isotope ratio mass spectrometer (GVI, Manchester, U.K.) interfaced to a multiflow equilibration unit (GVI, Manchester, U.K.). The measured values were compared to predictions by the MK model and deviations were quantified as root mean squared error (RMSE). The MK model considers nine input fluxes (all boxes above the cow in Figure 1 except 'Precipitation' and 'Soil water') and seven output fluxes and the underlying physiological processes (all boxes below the cow in Figure 1). As input to the MK model, information on feed composition (grass silage, hay, maize silage, concentrates, and fresh grass both pasture and cut) was obtained from interviews with the farmers. Weather data and $\delta^{18}O$ of precipitation were obtained from nearby weather stations and isotope stations.

Results and discussion

Average proportions of concentrate feed, conserved grass (silage or hay), maize silage, cut grass, and pasture grass represented 12, 49, 7, 10 and 22% of cow diet, respectively, but there were considerable differences between farms and seasons (Figure 2), which influenced the $\delta^{18}O$ of milk water. Farms with constant feeding (e.g. farm 14) exhibited less isotopic variation of milk water compared to farms where feeding varied seasonally (Figure 3). However, despite the large difference in feed composition, all farms showed comparable seasonality with $\delta^{18}O$ being higher in summer than in winter (Figure 3). This indicated a prominent role of ambient conditions on $\delta^{18}O$ of milk water. Thus, $\delta^{18}O$ of milk water is influenced by many parameters related to plant physiology, feeding strategy, ambient conditions and animal physiology, which need to be integrated in a model like the MK model.

The MK model estimated differences between farms and seasonality of $\delta^{18}O$ in milk water successfully (Figure 3), although some uncertainties remained (RMSE = 1.1% on average of all 608 samples) that likely stem from animal behaviour, farmer behaviour and the large short-distance variations in event precipitation (amount and $\delta^{18}O$).

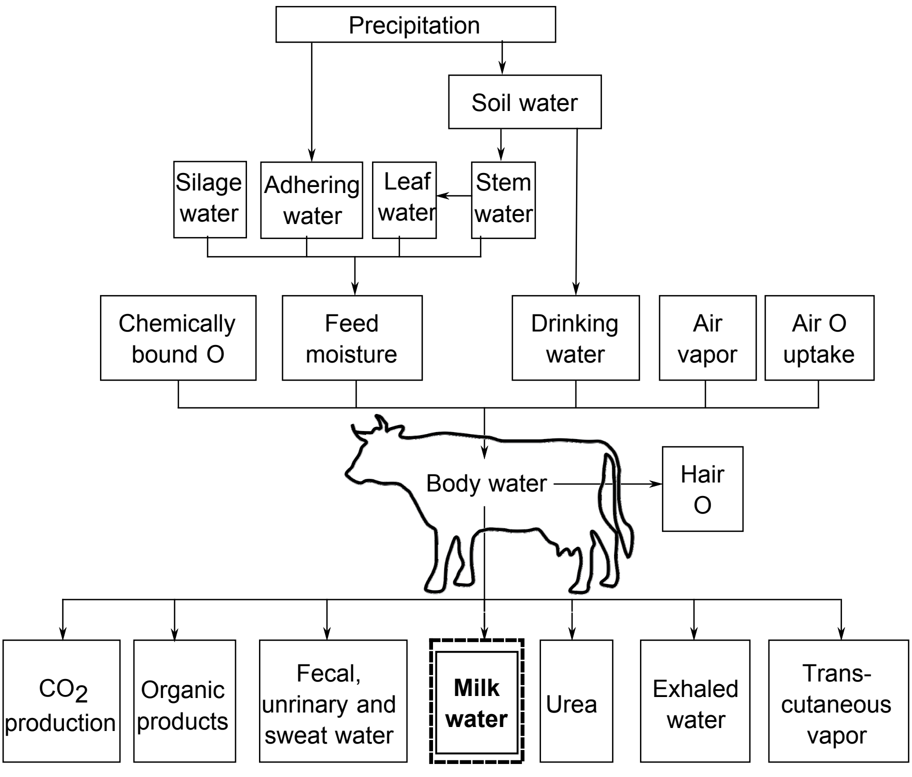

Figure 1. Main oxygen fluxes from precipitation to body water and (hair) protein considered in the MK model.

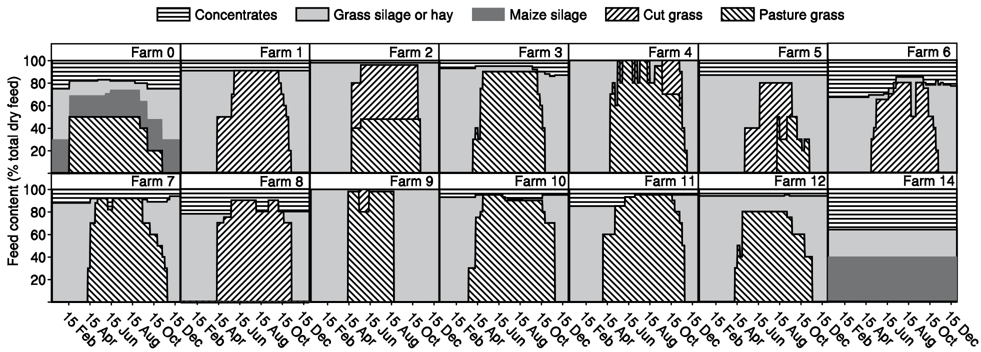

Figure 2. Seasonal variation of feed composition on 14 farms covering the range of 28 farms.

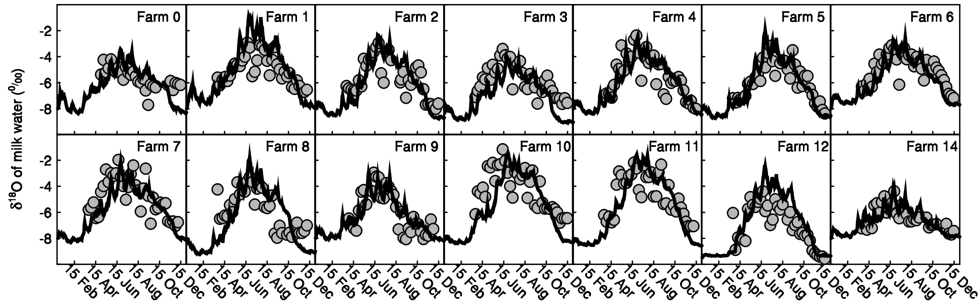

Figure 3. Measured (circles) and modelled (lines) $\delta^{18}O$ of milk water on 14 farms shown also in Figure 2.

Conclusion

The MK model suggests that the seasonal variation in milk and the feeding strategy should be definitely taken into account when using $\delta^{18}O$ for geographical origin assignment. The mechanistic character of the MK model offers the opportunity to analyse influences of various production parameters which is a prerequisite for identifying the origin of milk.

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GenoGrass: a low cost, high throughput genotyping platform for perennial ryegrass

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Abstract

Sequence based methods for surveying single nucleotide polymorphisms (SNPs) have a wide set of applications in perennial ryegrass breeding and genetics. Genotyping by sequencing (GBS) approaches are characterised by the ability to survey thousands of sites, however, some applications (e.g. varietal identification, association mapping with candidate genes) may not require such wide genome coverage, but would benefit from a GBS-based system that allowed the low cost analysis of thousands of samples at hundreds of loci. We are developing a low-cost GBS system for perennial ryegrass based on an approach called genotyping in thousands by sequencing (GT-Seq). The first iteration of this system is designed to interrogate SNPs at ~200 specific loci in the perennial ryegrass genome. Half these loci were identified as being highly predictive for heading date and crown rust resistance in genomic selection experiments involving a population of over 1,500 plants. The remaining loci were chosen to provide evenly-spaced genome coverage on the basis of the recently published assembly anchored by the perennial ryegrass genome zipper. We describe the identification of these loci and the subsequent design and testing of a primer set incorporating combinatorial barcodes that allow multiplexing of thousands of samples for PCR and subsequent NGS analysis.

Keywords: genotyping by sequencing, GT-Seq *Lolium perenne*, SNP

Introduction

Perennial ryegrass (*Lolium perenne*) is an economically important forage species for ruminant agriculture in global temperate regions. It is a cheap source of feed and is an integral part of milk and beef industries, reducing production costs and increasing profits (O'Donovan *et al.*, 2011). The use of molecular markers has the potential to accelerate the improvement of economically important traits in perennial ryegrass (Hayes *et al.*, 2013). Single nucleotide polymorphisms (SNPs) are abundant, flexible, biallelic molecular markers used for many applications in plant breeding. SNPs have been successfully applied as markers in genomic selection studies (GS) (Byrne *et al.*, 2017), diversity studies (Barth *et al.*, 2015), varietal discrimination (Byrne *et al.*, 2013) and association mapping (Velmurugan *et al.*, 2016) in perennial ryegrass.

These SNPs can be discovered and assayed by various approaches that are compatible with differing requirements, in terms of sample throughput and total number of SNPs surveyed per assay. Recently, genotyping approaches such as genotyping in thousands by sequencing (GT-Seq), based on combinatorial barcoding and massively multiplex polymerase chain reaction (PCR) enable targeting of a medium number (100 - 1000) of loci in thousands of samples (Campbell *et al.*, 2015). These inexpensive and high throughput assays enable targeted re-sequencing of specific loci that may have been discovered in a previous research phase. In this paper, we describe the development of such a genotyping platform, ('GenoGrass'), for deployment in various perennial ryegrass breeding and grassland management activities.

Materials and methods

The SNP identification for the experiment was mediated through reduced-representation genome sequencing of a collection of 1,582 individuals from the Teagasc perennial ryegrass breeding programme. This identified 217,563 SNP loci by virtue of alignment to scaffolds from the perennial ryegrass genome assembly (Pfeifer *et al.*, 2013; Byrne *et al.*, 2015). A subset of these scaffolds has been anchored to the perennial ryegrass genetic map via the perennial ryegrass genome zipper. Initially, 212 target amplicons were designed. A total of 79 of these amplicons were selected from GS experiments on the aforementioned population. The SNPs contained in these targets were identified as having high predictive ability for heading date and crown rust resistance. The remaining 133 amplicons targeted SNPs which occurred in anchored scaffolds at relatively even intervals across the seven perennial ryegrass linkage groups as defined by the genome zipper (Byrne *et al.*, 2015). Scaffolds confidently anchored using the genome zipper were selected and regions with high levels of variation were avoided to mitigate primer failure. Redundant polymorphisms identified in target amplicons were marked with IUPAC codes to aid primer design. Four hundred base pair regions were selected for primer design with SNPs of interest situated approximately in the centre of the amplicon.

Results and discussion

Primer pairs were successfully designed for 85% of amplicon targets identified initially. Length of target sequences post primer design ranged between 170 and 230 bp. Reasons for failure during primer design included presence of GC rich regions and an overabundance of polymorphisms present in the region of interest. Targets which failed during the primer design phase, including those derived from the GS datasets, were replaced with targets containing randomly selected SNPs that were anchored to the genome zipper. The final array consisted of 192 target amplicons, as outlined in Table 1. In total, 177 targets were anchored to the genome zipper, 153 with stringent parameters for anchoring and 24 with non-stringent. Twenty four out of 36 targets from the heading date data set and 30 out of 33 targets from the crown rust data set were anchored. As outlined in the methods, the remaining 123 anchored amplicon targets were designed to give relatively even coverage of the perennial ryegrass genome based on their position on the perennial genome zipper (Figure 1).

The selected array of targets has potential applications in genomic selection, genetic mapping, investigating diversity and varietal discrimination. These applications are fundamental in perennial ryegrass breeding, both for decision making and quality control. These SNP markers have advantage over other commonly used marker systems in grasses such as simple sequence repeats (SSRs) (Hodkinson *et al.*, 2013) because of their transferability among laboratories and because they are based on nucleotide characters rather than amplicon length differences. Potential also exists to utilise this array for monitoring changes in genotype performance and composition, particularly in swards composed of several cultivars.

Table 1. Number of targets per marker group and number of targets anchored confidently in the genome zipper.

Marker Group	Number of targets	Status in genome zipper	Number of targets
Crown rust	33	Non-stringent	24
Heading date	36	Stringent	153
Linkage group	123	Unanchored	15
Total	192	Total	192

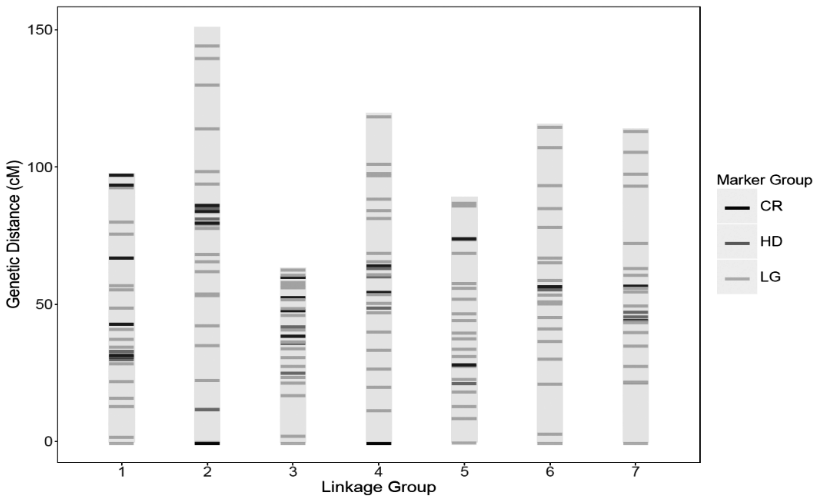

Figure 1. Distribution of targets across seven perennial ryegrass linkage groups in centimorgans (cM). Marker groups = crown rust (CR), heading date (HD) and linkage group (LG).

Conclusion

GenoGrass offers a method of genotyping at a lower cost per sample with high sequencing coverage of each locus. We envisage deploying this inexpensive genotyping platform for a variety of applications in perennial ryegrass breeding.

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UAV based mapping of grassland yields for forage production in northern Europe

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Abstract

In order to establish the relationship between spectral reflectance and grass yield, we used a UAV-based hyperspectral camera and ground-based spectroradiometry to image a number of cultivated grasslands of different age and productivity in northern Norway. In addition, samples were taken to determine biomass and grass species composition. We investigated a number of vegetation indices as well as regression analysis to identify which spectral reflectance features can be used to map crop yield. We found poor relationships between NDVI and yield, but were able to obtain an acceptable relationship using all 15 available bands in the visible-near infrared range. Bands in the near infrared appear to contain most of the information related to yield.

Keywords: yield, biomass, UAV, multispectral remote sensing, Norway

Introduction

Grassland cultivation for animal feed is the key agricultural activity in northern Norway. Even though the growing season has increased by at least a week in the last 30 years, grassland yields appear to have declined, probably due to more challenging winter conditions and changing agronomy practices. The ability of local and regional crop productivity forecasting would assist farmers with management decisions and would provide local and national authorities with a better overview of productivity and potential problems due to e.g. winter damage. Remote sensing technology has long been used to estimate and map the variability of various biophysical parameters, but calibration is important. Both Honkavaara *et al.* (2013) and Geipel and Korsaeth (2017) showed the potential of using airborne hyperspectral remote sensing to predict grassland yield by measuring experimental plots of the same age and grass composition but with varying fertilisation levels. However, it is well known that grass composition will change with age, soil conditions and climate, and grassland fields typically show significantly more variation than experimental plots. In this paper we investigate how well airborne hyperspectral remote sensing can predict yield in real cultivated grasslands of different ages, botanical composition and productivity in northern Norway. The results are then used to discuss the potential of satellite based multispectral sensors to map crop yield.

Materials and methods

The measurements were carried out in three cultivated grass fields on the Malangen peninsula in northern Norway, at 68.45°N 18.90°E, in 2017. The fields varied in age and, as a result of this, also in botanical composition. The measurements were collected immediately prior to the first cut in early July. We used a multirotor UAV with a Rikola multispectral camera recording 15 bands in the visible and near infrared (NIR) part of the spectrum (500 - 900 nm) to map the variation in spectral reflectance. In addition, the UAV carried a broad band irradiance sensor measuring downwelling irradiance, and a normal EOS M camera. The images were captured from a height of about 100 m and speed of 2-3 m s^{-1}. Before each flight, three dark current images were taken by covering the lens with a thick black cloth, and three images of a set of three different grey level spectral reflectance targets with known reflectivities of ca 95, 43 and 22% (Sphere Optics) were also taken. In each field, five - eight ground control targets were measured with a Topcon GR-5 RTK GNSS receiver. Immediately after the flights, we measured the spectral reflectance using an ASD Fieldspec 3 (350 – 2,500 nm) at 25 sample locations in each field. In addition, species composition and phenology were estimated and biomass was measured at each sample location.

Pre-processing of the multispectral data was achieved in several steps: (1) calibration of the individual images to radiance, correcting for the dark current and lens distortion; (2) correction for the variation in light intensity during the flight, using the irradiance measurements for each image; (3) creation of single band orthomosaics using Agisoft Photoscan; (4) radiometric calibration: conversion from radiance to reflectance by using an empirical line calibration based on the measurements of the spectral reflectance targets; (5) the single band orthomosaics were coregistered and combined into an orthorectified hyperspectral cube with a spatial resolution of 7.5 cm; and (6) average reflectance spectra were extracted for a 1 m diameter area around each recorded sample location. The pre-processing was done using calibration software supplied by the camera manufacturer and python. Data analysis was carried out using python, QGIS and XLSTAT. We used partial least squares (PLS) regression and multiple linear regression on the extracted spectral data, and single linear regression on selected calculated vegetation indices. In this paper we present two indices: the commonly used normalised difference vegetation index (NDVI): $(R_{783} - R_{665}) / (R_{783} + R_{665})$; and the red edge inflection point (REIP): $700 + 40 \times (((R670 + R780) / 2) – R700) / (R740 – R700)$.

Results and discussion

Dominant grass species included *Phleum pratense*, *Festuca pratensis*, *Poa pratensis*, *Elytrigia repens* and *Agrostis* but their relative quantities varied across and between the fields. *Ranunculus repens* was locally significant. The dry weight of the vegetation samples varied between 1,680 - 6,180 kg ha^{-1} (42 - 157 g 0.25 m^{-2}). The single band NIR (750 nm) image (Figure 1) shows some of the variation within two of the measured fields. The NDVI and REIP show poor relationships with yield, giving R^2 values of 0.16 and 0.38, respectively (Table 1). The multiple linear regression using all 15 bands provided a much better relationship, with an R^2 value of 0.69 (Figure 2). PLS and multiple linear regression modelling indicated that two bands in the NIR, at 842 nm and 750 nm, contained most of the information. Using a ratio of these two bands gave a correlation with an R^2 value of 0.45.

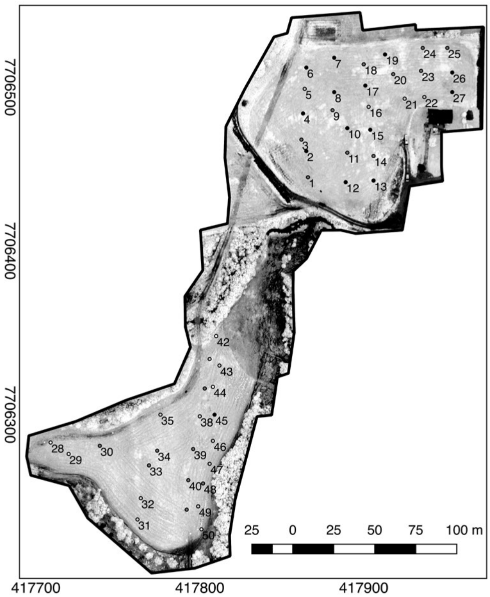

Figure 1. NIR (750 nm) image with sample locations.

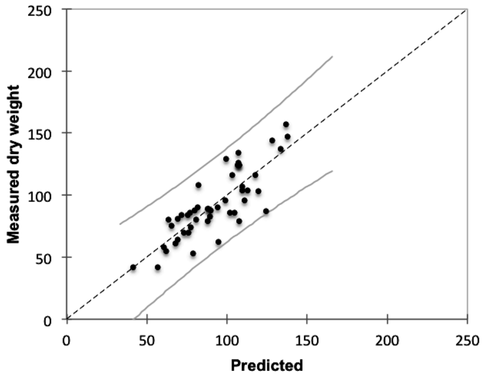

Figure. 2. Multiple linear regression model using all 15 bands. Solid lines indicate 95% confidence interval.

Table 1. Regression modelling results.

	n	R^2	RMSE (%)
NDVI	48	0.16	27.3
REIP	48	0.38	23.4
R_{750}/R_{842}	48	0.45	22.1
15 bands	48	0.69	19.8

Compared to the results reported for experimental fields (Geipel and Korsaeth, 2017), the yield prediction for real fields using remote sensing methods is more difficult. Geipel and Korsaeth (2017) showed that the different grass species can have distinct spectral differences. The variation in botanical composition that was observed both within and between fields of different ages and quality will, therefore, induce an additional spectral complexity, masking the relationship between spectral reflectance and yield. However, using all 15 available bands improved the model and shows that at least a coarse prediction would be possible. The results indicate that the use of NDVI from satellite imagery is unlikely to give good estimates of yield for fields of varying ages, but that a combination of available bands in the visible-NIR range may be appropriate after calibration. In particular, Sentinel-2 bands 6 (740 nm) and 8 (842 nm) may hold information related to biomass.

Conclusion

The wide variation in botanical composition in cultivated grass fields in northern Norway, due to differences in age, soil quality and climate, compared to experimental plots, masks the reported relationships between spectral reflectance and yield. For these more diverse fields, a combination of bands in the visible-NIR range is needed to provide a yield prediction.

Acknowledgements

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Using RGB remote sensing for biomass prediction in temperate grassland

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Abstract

Grassland monitoring techniques which can predict biomass yield over the whole farm enable the farmer to make site-specific management decisions. Crop biomass and plant height are highly correlated with each other and thus, crop surface height can be used for yield prediction. Non-destructive remote sensing tools are useful for obtaining spatial information on plant height on larger scales. In this study a red, green, blue (RGB) camera on a small unmanned aerial vehicle (UAV) was used for yield prediction in a temperate grassland experiment. The experiment was established in 2016 with two legume-grass mixtures (clover-grass, lucerne-grass) as well as in pure stands of legumes and grasses. RGB imaging was carried out every second week for estimating the growth rate of the grasslands and before each harvest (4 cuts). In parallel, reference data for biomass yield and manual height measurements were taken. 3D crop surface models generated from RGB imaging based measurements were used for calculating the crop surface height. The biomass yield was predicted with satisfactory results.

Keywords: remote sensing, RGB, biomass prediction, temperate grassland

Introduction

In order to use temperate grassland efficiently and effectively as fodder or as a bioenergy feedstock, detailed information about its quantity and quality at various spatial and temporal scales is mandatory. In general, crop biomass is positively correlated to its plant height (Lati *et al.*, 2013), therefore, crop surface height (CSH) plays a significant role in yield prediction.

Remote sensing is a useful non-destructive tool for obtaining spatial information on plant height, which allows a rapid assessment of aboveground biomass with relatively low costs. A new method to easily and quickly cover large areas involves a red, green, blue (RGB) imaging process from a digital high-resolution camera on a small unmanned aerial vehicle (UAV). By photogrammetric structure from motion (SfM) processing of these digital images into point clouds, 3D spatial data can be generated. So far, only a few studies exist on RGB UAV imaging in agricultural crops. In a study of Bendig *et al.* (2014), it was shown that there is a relationship between plant height, biomass and RGB imaging in 18 different summer barley cultivars. Schirrmann *et al.* (2016) found that the calculated plant height measured by RGB imaging at three different growth stages of winter wheat was significantly correlated with the actual plant height and biomass. These studies clearly indicate that there is a relationship between biomass and RGB imaging in homogeneous crops. To the knowledge of the authors, research on biomass yield prediction by crop height using RGB UAV imaging has not been conducted in heterogeneous temperate grassland up to now.

Materials and methods

The study was carried out at the organic experimental farm Neu-Eichenberg of the University of Kassel (51°23' N, 9°54' E, 227 m above sea level), 6 km north of Witzenhausen in northern Hesse, Germany. The soil is a sandy loam with 3.6% sand, 73% silt, 23.4% clay and 2% humus. The mean annual precipitation and daily temperature of the site is 728 mm and 8 °C, respectively. Field plots (1.5 × 10 m) of clover-grass and lucerne-grass in mixtures as well as pure stands of legumes and grasses were sown in autumn 2016 in four replicate blocks. All plots were harvested on four occasions in the following year (17 May 2017, 26 June 2017, 08 August 2017, 09 October 2017) with a Haldrup forage harvester at a cutting height of 5 cm. At the same time, biomass samples for fresh and DM yield (area of 50 × 50 cm; dried at 105 °C) were taken manually, twice in every plot.

RGB images were taken with an UAV (DJI Phantom 3 Professional; Shenzhen, Guangdong, China) using auto-pilot by means of Pix4Dcapture software (Pix4D SA; Lausanne, Switzerland). These flights were carried out at each harvest (four flights) and every second week (six flights). For each flight, images were taken in a grid pattern at a height of 10 m and seven black and white targets, as portable ground control points were evenly distributed and set up in the field, which were used for georeferencing the images after each flight. The coordinates of the point cloud were measured using a Leica DGPS. At flight occasions when harvesting was carried out, biomass samples were taken manually as reference data on an area of 25× 25 cm in each plot. Manual height measurements (50 measurements per plot) were also taken with a ruler at every harvest.

The RGB imaging data was rectified for geometric and radiometric errors. 3D point clouds from the RGB images were generated for each data set using the SfM-based imaging processing software Agisoft PhotoScan to calculate the digital surface model (DSM). Quantum Geographical Information (QGIS) software was used for the next steps. To provide a digital elevation model (DEM), ground points in the path next to the plots were selected, which were interpolated to provide a continuous ground surface model over the whole field. The CSH was calculated by subtracting DEM from DSM. Subsequently, a mean CSH value for each plot was calculated. Dry matter yield had to be square root transformed to achieve normal distribution of data. All statistical analysis for linear regression models were performed by using the R programming language (R Foundation for Statistical Computing 2017).

Results and discussion

The major objective of the research was to examine the relationship between total biomass and RGB imaging in temperate grassland. As clover and lucerne-grass were investigated at various growth stages through the vegetation period, DM yield varied widely. For the manual height measurement linear regression predicted total DM yield with an adjusted coefficient of determination (adj. R^2) of 0.62 and a standard error (SE) of 0.31 (Figure 1). RGB imaging correlated slightly better with DM yield (adj. R^2 = 0.69, SE = 0.27).

Regression analysis between ruler measurements and RGB imaging correlated well and revealed a highly significant relationship with an adj. R^2 of 0.56 and SE of 11.02.

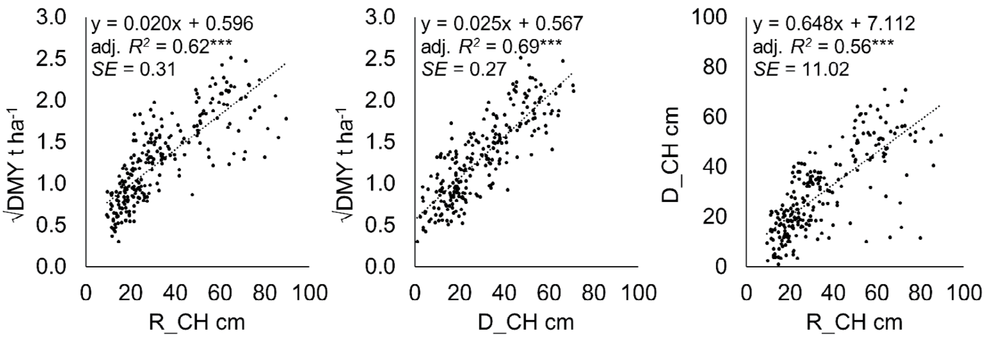

Figure 1. Linear regression models for dry matter yield (√DMY t ha^{-1}) and crop height from manual height measurements (R_CH cm) and RGB imaging (D_CH cm) through the vegetation period (*** $P < 0.001$).

Malambo *et al.* (2018) found that in a field experiment with maize and sorghum, the growth stadium of the plant affected the prediction accuracy of SfM-based crop height detection. In our study, sward growth in summer (2nd cut) was strongly affected by drought, which led to an earlier generative phase and, therefore, to many elongated shoots with visible ears and narrow leaves. If the data of the 2nd cut (26 June 2017) were excluded from the dataset, adj. R^2 and *SE* showed an improvement with 0.70 and 8.84, respectively (data not shown). As manual height measurements were carried out only for a limited number of points in the field, this method is more sensitive towards single protruding shoots. RGB UAV imaging is less susceptible due to measurements of the whole area and the position of the camera.

Conclusion

RGB UAV imaging is a useful non-destructive method for biomass prediction in temperate grassland. This study indicates that SfM from RGB UAV imaging is more accurate under heterogeneous sward conditions than the manual height measurement. Furthermore, RGB imaging with a UAV is a suitable alternative due to the time and labour requirement associated with manual height measurement. Combining height data with other remote sensing techniques, like hyperspectral or laser sensors, may further improve the prediction of quantity and quality of yield in temperate grassland.

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PastureBase Ireland: a grassland decision support system and national database

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Abstract

PastureBase Ireland (PBI) is a web-based grassland management application, incorporating a dual function of grassland decision support and a centralised national database to collate commercial farm grassland data. The database spans across ruminant grassland enterprises of dairy, beef and sheep. A range of decision support tools are available within the application to assist the decision making process at farm level. Individual farmers enter data through the completion of regular pasture cover estimations across the farm, allowing the performance of individual paddocks to be evaluated within and across years. Individual paddock outputs from 75 commercial farmers, as active PBI users, were evaluated across a two year period (2014 to 2015). The analysis demonstrated significant increases in DM yield from 2014 to 2015. It also indicated greater variation in pasture growth across paddocks within farms than across farms. This analysis suggests that there is significant scope to increase pasture growth within farms through focusing on the reasons for underperforming paddocks within a farm.

Keywords: PastureBase Ireland, grassland measurement and management

Introduction

The removal of European milk quota restrictions in April 2015 has provided Irish dairy farmers with the opportunity to increase milk output nationally for the first time in a generation. In Ireland, the profitability of such expansion should centre on increasing grass growth and grass utilisation at farm level (Shalloo *et al.,* 2011). While significant expansion is expected with the removal of milk quota (Läpple and Hennessy, 2012), such expansion coupled with volatile global milk markets means farmers must develop sustainable milk production systems, focused on technical and financial efficiencies (Kelly *et al.,* 2012). Research has shown that each 10% increase in the percentage grazed grass as a proportion of the overall diet of a dairy cow reduces the cost of milk production by 2.5c/l (Dillon *et al.,* 2005). This is further emphasised by Finneran *et al.* (2010) who reported that grazed grass is the most cost effective feed available to all ruminant livestock production systems with a relative cost ratio in 2010 of grazed grass to grass silage and to concentrate of 1:1.8:2.4. Many studies have highlighted the potential for increased output and productivity from grazed grass through a focus on key components of different aspects of grass based systems. PastureBase Ireland (PBI) has the capability of providing support for grassland management decisions through the provision of decision support tools and also has the potential to contribute to new research in grassland management. The objective of this study is to describe, evaluate and demonstrate the utility of PBI as a web-based grassland decision support tool for use on grassland farms in Ireland.

Materials and methods

The PBI application incorporates a web-based PC or smart phone enabled user interface linked to a grassland database, which has a dual function of providing real time decision support for farmers and farming practitioners, while capturing farm grassland data in the background for benchmarking and research purposes. The system operates with the individual farm paddock as the basic unit of measurement for the farm. The system is operated by the farmer entering the grassland information through the web front end, and thus the accuracy and usefulness of the system is determined by the level and accuracy of the data recorded by the user. The farmer builds a profile for each paddock through a user friendly intuitive interface by entering information on paddock size, location, soil type, altitude, drainage, etc., which can then be linked to paddock performance over time. Data on paddock characteristics can potentially assist in explaining how individual paddocks perform. These data also allow the farm to be categorised at paddock, farm and regional level for the purpose of benchmarking or as part of on-going research. The farmer enters weekly pasture cover estimates, graze dates and livestock details, which PBI can use to produce a series of daily and periodic outputs. The utility of the system was demonstrated by analysing annual and seasonal DM yields of commercial farms across 2014 and 2015, with particular interest in the variation within and between farms. This analysis was completed using a subset of 75 PBI users, with an average of 34 paddocks per farm. Each farmer was required to have at least 30 pasture cover estimates completed in each year to ensure a high level of accuracy in the data. The information was downloaded from the PBI database to Microsoft Excel to facilitate analysis. The data was categorised by spring (1 February to 10 April), mid-season (11 April to 6 August), autumn (7 August onwards) and total annual DM yield, as defined by McEvoy *et al.* (2011). The DM yield mean and standard deviation were calculated at farm and paddock level across all 75 farms containing 2,547 paddocks, across the seasons for each year. A t-test was then completed using the SAS 9.3 statistical analysis program (SAS Inst. Inc., Cary, NC) to determine the significance of the differences in DM yield between 2014 and 2015.

Results and discussion

The analysis indicates variation in cumulative pasture growth across farms and across paddocks within farms for 2014 and 2015 (Table 1). The seasonal distribution of pasture growth across the spring, mid-season and autumn periods were 8, 52 and 40%, respectively, in 2014. There was a significant increase in total farm pasture growth in 2015 compared to 2014 ($P < 0.05$). On a seasonal basis, the spring and autumn (but not mid-season) pasture growths were significantly higher ($P < 0.01$) in 2015 compared to 2014. The seasonal distribution of growth in 2015 across the spring, mid-season and autumn periods were 9, 50 and 41%, respectively. The results indicate greater variation across paddocks within farms than across farms, with an annual higher standard deviation (Table 1) at paddock level than at farm level in 2014 and 2015. This would suggest that potential exists to increase growth across paddocks within farm. The reasons for this underperformance must be explored. It may be caused by suboptimal soil nutrient status, poor grass cultivars or inadequate grazing management in those particular paddocks. The use of PBI allows underperforming paddocks to be identified and targeted action to be taken at farm level.

Increasing the information on seasonal and annual differences within and across farms will help reduce variation through determining the most suitable corrective measures e.g. reseeding, soil fertility, etc. The utility of the PBI system is also observed under this evaluation process in terms of its ability to act as a centralised database for research data. Analysis of this type of data over time will allow identification of the main factors affecting changes in pasture growth. PBI provides instant collection and storage of live data with outputs that are produced in real time, as well as having centralised data storage mechanisms.

Table 1. Mean and standard deviation of PastureBase Ireland commercial farm data for the DM yield of 75 farms on an annual and seasonal basis for 2014 and 2015.

		Spring kg DM ha^{-1}	Mid-Season kg DM ha^{-1}	Autumn kg DM ha^{-1}	Total kg DM ha^{-1}
2014	Farm	843 (± 380)	5,478 (± 1,693)	4,274 (± 1,066)	12,733 (± 3,026)
	Paddock	824 (± 582)	5,363 (± 3,201)	4,190 (± 1,766)	12,452 (± 4,712)
2015	Farm	961 (± 317)	5,588 (± 1,388)	4,567 (± 1,188)	13,197 (± 2,753)
	Paddock	943 (± 557)	5,460 (± 3,006)	4,492 (± 1,858)	12,928 (± 4,721)

Conclusion

The study has demonstrated the potential of the newly developed PBI system to provide decision support for farmers while collating large quantities of grassland data. For farmers, the initial direct impact of PBI will come from the advancement of the decision making process through regular pasture measuring and budgeting on farm. These management practices will allow farmers to enhance their grazing management skills and ultimately contribute to substantial increases in both productivity and profitability on pasture-based farms.

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Producing solid biofuels from semi-natural grasslands invaded by *Lupinus polyphyllus*

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Abstract

The negative effect of invasive neophytes on natural ecosystems is a global problem, as it often leads to a loss of biodiversity in the invaded plant communities. In the case of *Lupinus polyphyllus* there is an additional negative effect on forage quality as the legume contains harmful alkaloids. This biomass may be usable as an alternative input feed for solid fuel production via the integrated generation of solid fuel and biogas from biomass (IFBB), which works through hydrothermal conditioning and mechanical separation. We investigated how the silage to water ratio in the hydrothermal conditioning influences solid fuel quality. Biomass infested with *L. polyphyllus* was harvested, cut to 4 cm fibre length and nine silages were prepared. After ensiling they were hydrothermally conditioned with 40 °C warm water with three different silage to water ratios (1:2, 1:4 and 1:8). After hydrothermal conditioning, the samples were mechanically pressed. Silage and press cake were analysed for elements harmful for combustion (N, S, K, Mg, Cl). The parent silage had the highest concentration of harmful elements. Adding more water to the hydrothermal conditioning step led to higher reductions of harmful elements, although the decrease in element concentration was not always statistically significant.

Keywords: semi-natural grasslands, *Lupinus polyphyllus*, energy

Introduction

Semi-natural grasslands are hotspots of biodiversity but are increasingly endangered by intensification and cessation of traditional management (Poschlod *et al*., 2005). In addition, invasive plant species, such as the legume *Lupinus polyphyllus* Lindl., have invaded semi-natural lower mountain grasslands, as e.g. the UNESCO biosphere reserve 'Hohe Rhön' in Germany. The biosphere reserve consists of semi-natural grassland communities adapted to low nutrient availability, such as mountain hay meadows and species rich *Nardus* grasslands. To maintain biodiversity a 2-cut mowing regime with removal of harvested material would be necessary (Jaquemyn *et al.*, 2003). However, in the case of *L. polyphyllus*, utilisation as forage for ruminants is hindered by toxic alkaloids (Veen *et al.*, 1992). To maintain biodiversity in semi-natural grasslands, it is necessary to find a use for the biomass, which is flexible in terms of cutting date and forage quality and also insensitive to toxic compounds. One option is the Integrated Generation of Solid Fuel and Biogas from Biomass (IFBB, Wachendorf *et al*., 2009). The system produces a press fluid for anaerobic digestion and a press cake (PC) for combustion. The biomass is conserved as silage, followed by a hydrothermal conditioning step and a subsequent separation. We investigated the effect of different ratios of water to silage added within the hydrothermal conditioning stage on the fuel quality of the PC.

Materials and methods

Silage bales were produced from the biosphere reserve 'Rhön', Germany. The samples were harvested and conserved in August 2015 and stored. They were opened and processed in April 2016. Material infested with mould was removed. Material of two bales was mixed and cut with a maize chopper to approximately 4 cm fibre length. The material was then filled into nine polyethylene barrels of 60 l with approximately 15 kg of silage per barrel. The 15 kg quantities of silage were weighed and put into hydrothermal conditioning. Three ratios of silage to water were tested, 1:2 (15 kg silage : 30 kg water), 1:4 (15 kg silage : 60 kg water) and 1:8 (15 kg silage : 120 kg water) and this was replicated three times. The hydrothermal conditioning was followed by mechanical separation with a screw press. The screw had a pitch of 1:6 and a rotational speed of 6 rpm. The cylindrical screen encapsulating the screw had a perforation of 1.5 mm. The resulting press cakes were collected for analysis. Dry matter was determined by drying at 105 °C in a drying oven for 48 h. Ash concentration was measured by incineration of a dried subsample at 550 °C in a muffle furnace, volatile solids were defined as DM minus the ash concentration. Press cake samples were dried for 48 h at 65 °C for elemental analysis. Samples for elemental analysis were ground with a cutting mill to pass a 4 mm sieve and, subsequently, with a sample mill to 1 mm. X-ray fluorescence analysis was conducted to determine concentrations of Cl, K, Ca and S. Concentrations of C, H and N were determined with an elemental analyser.

A one-way Analysis of Variance (ANOVA) was carried out to test for differences between the Ash, N, S, K, Ca, and Cl concentrations of the PCs with different silage to water ratio in hydrothermal conditioning. The assumptions of ANOVA were tested by using the Shapiro-Wilk-test for normality of distribution of residuals and the Levene's-test for the equality of variances. All assumptions were met, except for the Cl concentration in PC, where the Shapiro-Wilk-test indicated a violation of the assumption. Tukey-HSD test was carried out as a post-hoc test.

Results and discussion

The *L. polyphyllus* infested silage showed high concentrations of ash and other elements inconvenient in combustion. The K, S and Cl values are especially too high for the silage to count as an adequate solid fuel, as it would very likely cause problems with emissions, corrosion and ash slagging. The IFBB procedure reduced the amount of minerals harmful for combustion and thereby produced a solid fuel adequate for combustion. The highest reduction was achieved for Cl and K; lower reductions were achieved for Ash, N and Ca (Table 1).

Reduction in elemental concentration varied with the different silage to water ratios, with increasing reductions being associated with the higher amount of water in the hydrothermal conditioning. The differences between the concentrations in the PC were statistically significant in the case of N, K and Cl (Table 1) but not for Ash ($P = 0.09$), S ($P = 0.58$) and Ca ($P = 0.99$). In all cases the 1:8 ratio led to the lowest concentration in the PC, and the concentrations were different between all three ratios, except for K and Cl. The concentrations of N proved different for the 1:8 to 1:2 treatments.

The guiding value for unproblematic combustion was reached for Cl in the case of all three silage to water ratios, but the 1:4 and 1:8 ratio ensured that not only the average Cl concentration was below the threshold, but the Cl concentrations of all samples. The S and N were both reduced but the reduction was

Table 1. Arithmetic means of elemental concentration in silage and press cakes produced with different silage to water ratios and results of the ANOVA and TukeyHSD post-hoc test.

	Silage	PC 1:2	PC 1:4	PC 1:8	Guiding value [1]	ANOVA *P* value	Tukey HSD 1:2 / 1:4 / 1:8
Ash (g kg^{-1} DM)	108.4	72.4	68.4	68.2			
N (g kg^{-1} DM)	20.2	17.3	16.7	16.4	6.0	0.025	a/ ab / b
S (g kg^{-1} DM)	2.7	1.3	1.3	1.2	1.0		
K (g kg^{-1} DM)	13.7	2.8	2.0	1.5		<0.001	a / b /c
Ca (g kg^{-1} DM)	16.5	11.7	11.7	11.7			
Cl (g kg^{-1} DM)	8.1	0.9	0.6	0.4	1.0	<0.001	a / b /c

[1] Guiding value for unproblematic combustion according to Obernberger *et al.* (2006).

not sufficiently high to meet the guiding value for unproblematic combustion. In the case of S, the mean values were very close to the guiding value so that the risk of corrosion in the combustion unit might still be tolerable. The N content in the press cake was still above the value but modern burners with air staging should ensure the combustion of biomass with these N concentrations without producing NO_x emission above legal thresholds (Obernberger *et al*., 2006).

Conclusion

The experiment showed that the IFBB system improved the solid fuel quality of *Lupinus polyphyllus* infested biomass. Solid fuel quality is further improved with higher amounts of water used within the hydrothermal conditioning stage of the system. This is due to the higher reduction of undesirable elements such as N, K and Cl with increased water addition.

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Feasibility of UAV based low-cost monitoring in a horse grazed grassland

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Abstract

The feasibility of low-cost unmanned aerial vehicle (UAV) based monitoring for horse-grazed grassland was tested, as previous experiences from experimental grassland monitoring sites are promising. For the detection of spatio-temporal dynamics in sward structure of horse grazing sites, we used a low-cost UAV-based survey approach. These surveys were conducted on a monthly basis during 2017, on a study site with three different paddocks managed in a semi-rotational grazing system. Sward height changes with a geometric resolution of 50 mm were calculated by applying a point cloud comparison. The high resolution point clouds were derived by the structure-from-motion approach. Derived sward height changes of the first three periods fit to visual observations, as well as rising plate meter measurements of the first two periods. A more stratified design with increased number of ground truth points should be applied to distinguish patch types more exactly and link these to vegetation composition.

Keywords: UAV, low-cost, sward height estimation, monitoring, rising plate meter

Introduction

Low-cost unmanned aerial vehicles (UAV) have potential to be used to document and monitor sites, as these devices are becoming more usable and affordable. However, grazed grasslands, as a land-use system with distinct spatio-temporal dynamics in sward structure due to livestock's patch grazing behaviour are still quite challenging to monitor. Horses are observed to create and maintain distinct patch structures due to their pronounced grazing effect (Schmitz and Isselstein, 2013). In Europe, approximately 3.5 M ha of grasslands are managed in the framework of horse-husbandry (Jouven *et al.*, 2016). However, systematic research on the grazing impact of horses on vegetation and monitoring applications is sparse.

Therefore, we tested our experiences of applying low-cost UAVs on experimental grassland monitoring (Possoch *et al.*, 2016; Lussem *et al.*, 2017) in a horse grazed grassland area. The aim was to test the feasibility of UAV-based monitoring of sward height and patch structure, and link this to vegetation surveys.

Materials and methods

Our study site is located in the Rhenish Uplands in western Germany and covers about 1.5 ha. It is divided into three different paddocks, which are managed in a semi-rotational grazing system with a stocking rate of 0.4 LU $ha^{-1}y^{-1}$. In 2017, grazing started in May on paddock 'east' (Figure 1). Horses were relocated to the centre paddock on 15 June and to the west paddock on 17 August. No sward maintenance measures or fertilizers were applied. On paddock 'west' (Figure 1), sward disturbances due to wild boars required mechanical levelling in May. The north paddock was not grazed and was used for comparisons.

Paddocks were monitored monthly from May to September 2017 by a low-cost UAV (type: DJI Phantom 4). All surveys were georeferenced by ten targets measured by a highly accurate RTK-GPS. Images captured by the camera (resolution: 12.4 MP) of the UAV were used in the structure-from-motion approach and high-resolution point clouds representing the top canopy surface, as well as digital orthophotos were derived. The point clouds of the surveys were compared by the multiscale model

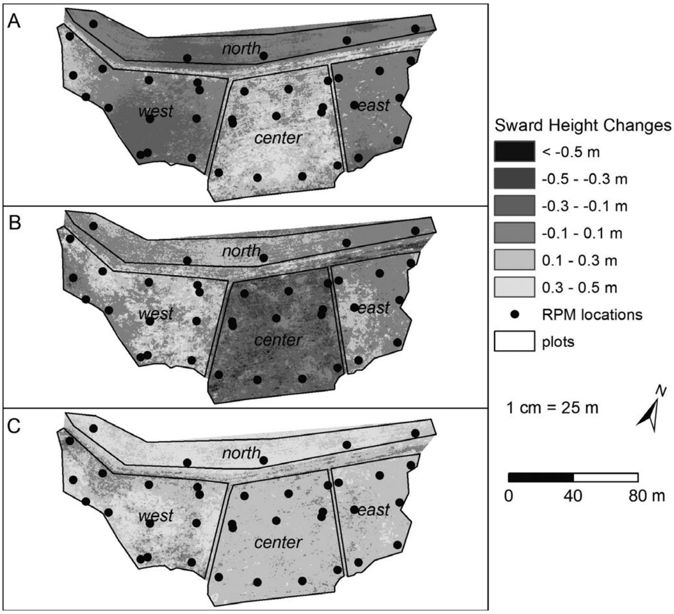

Figure 1. Maps of UAV-based sward height changes (SHC) between observations derived by differences of succeeding survey results (A:26 May 2017 – 23 June 2017; B: 23 June 2017 –22 July 2017; C: 22 July 2017 – 20 August 2017).

to model cloud comparison (M3C2) algorithm (Lague *et al.*, 2013) and results were interpolated for visualisation purposes to raster files with a geometric resolution of 50 mm. The results show the sward height change (SHC) between each time step.

For comparison, compressed sward height (CSH) was measured using a rising plate meter (RPM) on each survey at 40 equally distributed locations and differences between each date were calculated. A linear-mixed effects model (LME) was applied to compare both monitoring methods. The UAV-based SHC was modelled as a function of CSH based differences, date and their interaction. Paddock was included as a random intercept term. Pseudo R^2 and RMSE were calculated for the whole model, as well as for each time interval.

In July, a subset of 20 ground truth locations were chosen randomly and all plants of 1 m^2 were determined to species-level and their share on standing biomass was estimated. On each plot, species richness (SR), Pielou's evenness (J'), share of grasses, forbs and legumes was calculated.

Results and discussion

The derived results of three monthly grassland height changes between end of May and end of August 2017 are presented in Figure 1. Generally, UAV-based SHC is, as expected, higher than the RPM based CSH differences. Disagreements between both methods are shown for the west and centre paddock between May (A) and June (B), which might have been the result of the selected CSH locations (Figure 1), as well as measurement errors. LME confirmed significant correlation between monitoring methods, when UAV-based SHC was modelled as a function of CSH based differences ($P < 0.01$), time step ($P < 0.001$) and their interaction ($P < 0.001$). The R^2 of the whole model was 0.5 (RSME 0.12 m). Accuracy of fit between monitoring methods was different for each time step, with $R^2 = 0.02$ (RSME 0.15 m) in May - June, $R^2 = 0.5$ (RSME 0.13 m) in June - July and $R^2 = 0.3$ (RSME 0.06 m) in July - August. In contradiction to results of previous studies where a high correlation (R^2 = 0.86) between UAV-based SHC and CSH on experimental grassland (Lussem *et al.,* 2017) was observed, that cannot be confirmed here.

On the ground truth plots, a total of 88 species was found, which is relatively high in managed grasslands. Average SR was 42.2 (± 9.5) species per m^2 and J' varied between 0.34 and 0.69, indicating a strong local variation of local vegetation diversity. Since presence of different species affects height and density of swards, the observed strong diversity might explain the low R^2 between both methods, compared to experiences in experimental monoculture swards (Possoch *et al.*, 2016; Lussem *et al.*, 2017). Even though horses are known to create distinct heterogeneity in sward structure and species composition among patch types (Schmitz and Isselstein, 2013); in this study no significant differences were observed in species response variables among patches. Tall patch vegetation could be linked to *Centaurea jacea*, which is avoided by grazers and tended to dominate tall patches. However, patch types established by grazers could be visually detected in the map of height changes (Figure 1), even though very extensive grazing management of our study site did not lead to the distinct patch types that are commonly observed in horse grazed paddocks.

Conclusion

Results of sward height monitoring and biomass estimation indicated the challenges in monitoring diverse grassland swards in contrast to experimental sites. Such monitoring methods have potential but the sampling design has to be redefined. To distinguish patch types exactly and link this to vegetation composition, a more stratified design with increased number of ground truth points should be applied.

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Amazing Grazing: grass growth measurements with remote sensing techniques

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Abstract

Quantifying grass production is considered essential for adequate grassland management on grass based dairy farms. Spectral imaging with remote sensing techniques could be an alternative for labour intensive grass height measurements. In a cutting experiment with a factorial combination of nitrogen fertilisation and grass growth intervals, grass growth was measured with a Cropscan Multispectral Radiometer measuring light reflectance in eight or 16 bands (ground truth measurement). The aim of the experiment was to see whether vegetation indices can be used to quantify actual grass biomass. Preliminary results of the first year of the project showed that some vegetation indices were well related to grass yield. However, this relationship was best for individual cuts, meaning that correlations were changing during the growing season.

Keywords: Amazing Grazing, remote sensing, spectral imaging, grass, vegetation indices, DM yield

Introduction

Remote sensing technics are developing rapidly and are gaining ground in agriculture by the use of multispectral cameras integrated in satellite, drone or handheld appliances. Spectral imaging shows potential to get insight into actual grass production, as the rate of light reflection can be translated to vegetation indices. Proper prediction of biomass and its nutritional value is considered essential for modern day grassland management on grass based dairy farms. As such, spectral imaging techniques could provide an alternative for labour intensive grass height measurements. To explore these perspectives, an experiment on multiple types of soil (clay, sand and peat) was set up. The experiment was designed to run from 2016 to 2018 and the aim was to see whether vegetation indices could be used to quantify actual biomass. Grass growth was monitored with both nearby and remote sensing devices. This paper describes the preliminary results.

Materials and methods

In 2016, an experiment was commenced with the aim to relate weighed dry matter (DM) yield to spectral images. In order to achieve normal variation in hydrological conditions and mineralisation levels of nitrogen, the experiment was set up on a Dutch clay, sand and peat soil. A factorial combination of nitrogen fertilisation (0, 180 and 360 kg ha^{-1}) and grass growth intervals were provided to create various yield stages. The aim was to have a broad measuring range on one specific moment to relate spectral images to DM yield. The total number of plots was 24 per location (three nitrogen levels × four growth intervals per cut × two repetitions). The four growth intervals existed of three interim trimmings (weekly, each on six plots) and a 'final' cut of all 24 plots. The number of final cuts per location was five (clay and peat) to six (sand) and covered the entire growing season. The experimental plots were about 20 × 20 m in size to be visible on satellite and drone imagery. At the moment of the final cut, a day before harvest, light reflectance was measured with a calibrated Cropscan Multispectral Radiometer (MSR87, MSR16R). The clay (2016 - 2017) and peat (2017) location were measured in 16 bands between 460 - 1080 nm. The sand location was measured in eight bands between 460 and 810 nm, whereby five bands were corresponding with bands of the 16 bands Cropscan. Therefore, the equipment difference was not limiting data analysis. The reflection at 560 nm, 660 - 670 nm or 760 nm were combined with the reflection at 810 nm using several algorithms called vegetation indices. Four common vegetation indices were used, which included NDVI (Rouse *et al.*, 1973), WDVI red (Clevers, 1989), WDVI green (Bouman *et al*, 1992) and NDRE (Eitel *et al.*, 2010). The harvest was done by cutting two strips of 1.5 × 8 m per plot with a Haldrup™ harvester for experimental fields. Fresh grass yield was weighed and DM content was determined by drying grass samples for 24 hours in a stove at 70 °C.

Results and discussion

For the three locations, a relatively small range of light reflections was found at 460 - 560 nm and a relatively broad range of light reflections was found at 760 - 810 nm. Wavelengths higher than 810 nm did not give deviating results. For all five final cuts of the clay location (2016), the indices were plotted against DM yield (Figure 1).

The results could be fitted using an exponential relationship with R^2 coefficients between 0.34 and 0.61. WDVI red was best related to DM yield based on the calculated R^2 coefficient, although the difference between WDVI red and green was relatively small. However, due to a high variation in results, yield could not be predicted reliably using a single algorithm for the complete growing season. Furthermore, the relationships were different per location. An important improvement of the relationships could be realised by distinguishing the different cuts (Figure 2) per location.

The results showed exponential relationships with R^2 coefficients between 0.87 and 0.93 for cuts 1 - 4. However, by the end of the growing season, cut 5 WDVI red was hardly related to DM yield, because of low yields. Relatively high reflection percentages were related to relatively low DM yields in cut 2. Although it is not known why the correlation is changing during the growing season and between locations, a number of reasons should be considered. Possible explanations include a change in composition of biomass (N - content, DM content) leading to change in base absorbance. Similarly, the orientation of foliage triggered by grass length differences between cuts and flowering could influence reflectance. We expect further analysis to offer more insight into this matter. Furthermore, it has to be remarked that the current results are obtained under mowing conditions. Therefore, it is also the question how heterogeneity due to grazing will impact the correlations. Answering this question will be part of the Amazing Grazing project in 2018 (Schils *et al.*, 2018).

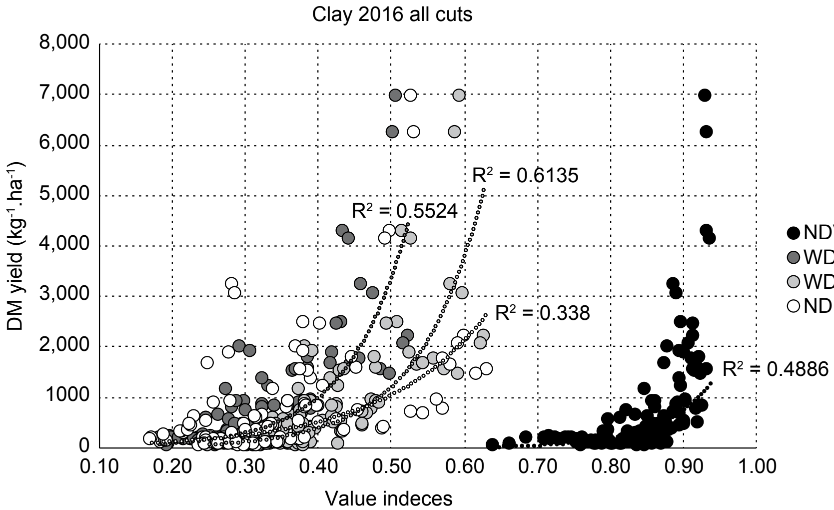

Figure 1. NDVI, WDVI green, WDVI red and NDRE plotted against DM yield for all cuts of the clay location in 2016.

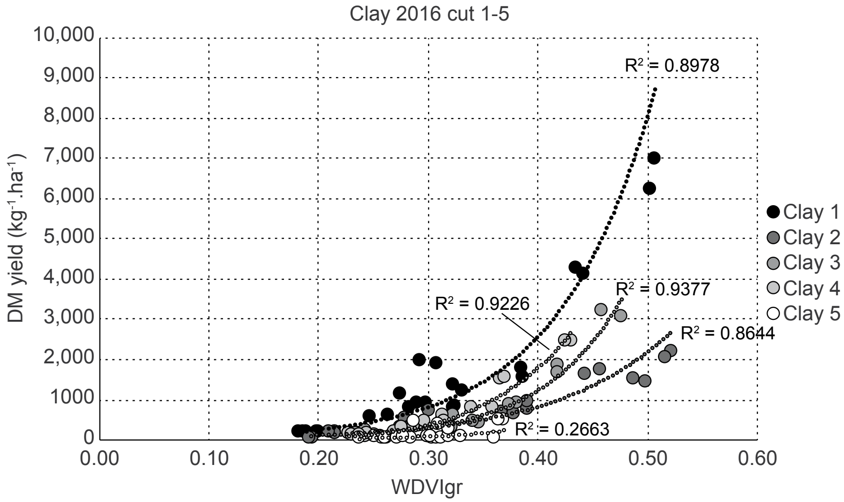

Figure 2. WDVI red plotted against DM yield per cut (1-5) for the clay location in 2016.

Conclusion

Preliminary results of the experiment showed that some vegetation indices were well related to grass yield. However, this relationship was best for individual cuts, meaning that correlations were changing during the growing season. Results varied per location. More insight into those matters is desired, as well as the impact of heterogeneity due to grazing. In the meantime, spectral imaging is helpful to get an insight into yield variation between grass plots and within grass plots under similar growing conditions.

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MSR87 and MSR16R, CropScan Inc., Rochester, MN, USA, http://www.cropscan.com

Novel baling foils and selected properties of preserved haylage

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Abstract

The aim of the study was to evaluate haylage quality made using six types of new generation foils, prepared with the addition of components facilitating their recycling and biodegradation. The influence of the foil on the following haylage parameters was evaluated: pH, water soluble sugars and dry matter content. Standardised laboratory methods were used for the evaluation of haylage on two dates: after four and 12 months from the date of bale formation. Studies were carried out in cooperation with the Centre for Animal Breeding in Osiek. The stretch film used for wrapping of haylage bales was produced by ERG Bieruń Folie, whose production formula was developed by the Central Mining Institute in Katowice. The largest dry weight loss (4.8%) was found in haylage wrapped with 8% zinc-based microbial component. The highest content of WSC (9.82%) was noted in haylage bales wrapped with a nanosilver component and may indicate a slower development of lactic acid bacteria.

Keywords: haylage, foil compounds, feed quality

Introduction

Winter feeding duration in Poland is about 200 days, while the summer feeding period is about 165 days (Stachowicz, 2010). Therefore, in the relatively short growing season, it is necessary to preserve the forage in sufficient quantities for the winter. At the end of 20th century, hay and silage production were the main means of conservation. Their production was characterised by high costs and large losses of nutrients. The bale wrapping process predominant today allows for better feed preservation and haylage storage over a long period of time, as well as reducing the influence of weather on production and storage (Coblentz *et al*., 2016). Production of haylage using foil increases the amount of waste materials because used silage film is difficult to recycle due to soiling with haylage that is difficult to remove (Rutkowska *et al*., 2002; Szterk and Mikolajczyk, 2007). An important feature that will be implemented in the production of this type of plastics will be its recyclability and biodegradability. The aim of the study was to evaluate the haylage quality produced in cylindrical bales using six new generation foils, which were prepared with the addition of components facilitating the recycling and biodegradation of the used foil.

Materials and methods

Haylage quality studies were conducted at the University of Agriculture in Cracow in cooperation with the Center for Animal Breeding in Osiek. Foils were produced by ERG Bieruń-Folie, whose production formula was developed by the Main Mining Institute in Katowice. The exact formulation of foils and the method of its production at this stage cannot be disclosed due to the preparation of the project application to the Patent Office.

Seven types of film were used:
A – standard foil available on the market;
B – with the addition of 3% microcellulose;
C – with the addition of 5% microcellulose;
D – with the addition of 5% nanosilver;
E – with 5% zinc-based microbial component;
F – with 8% zinc-based microbial component;
G – with microbial component 102631.

The reference point for evaluation was haylage produced using standard silage foil (A). The influence of the foil on the following parameters of haylage was evaluated: pH, water soluble carbohydrates (WSC) content and dry matter content. Standardised laboratory methods were used for the evaluation of haylage. Haylage was assessed at two time points: after four and 12 months from the date of bale formation. In the first assessment, two types of foil (B and C) with 3 and 8% of microcellulose were eliminated from further investigation because they did not represent an adequate oxygen barrier. The material used for the ensiling was a mixture of grasses and legumes: Italian ryegrass, perennial ryegrass, red fescue, white clover, as well as other species that made a small contribution to the sward.

Results and discussion

After four months of storage, the highest dry matter content was found in haylage wrapped with 5% silver-nanoparticle (D) (45.2%) and the lowest with zinc-based (F) microbial component – 8%, (40.2%) (Table 1). With other variants of the foil, the dry matter content in the haylage ranged from 41.1 to 44.1%. After a further eight months of storage, a decrease in dry matter content was observed in all analysed samples. The largest dry weight loss (4.8%) was found in haylage wrapped with 8% zinc-based microbial component (F). Similar values were noted in the bale wrapped with nanosilver component foil (D). In other cases the losses ranged from 0.7 to 1.6%.

The haylage after four months had similar pH and ranged from 4.27 to 4.42 (Table 1). After 12 months of storage, the pH of haylage made using five different types of foil decreased. The greatest differences were observed for haylage wrapped with foil with microbiological additives 102631 (G) and wrapped with the nanosilver component. In the other cases the differences were small and ranged from 0.04 to 0.06. The coefficient of variance was low, with values of 0.0032 and 0.0054 observed at the four and 12 month storage times.

The highest content of WSC (9.82%.) was noted in haylage bales wrapped with a nanosilver component (Table 1). A slightly lower content of WSC was noted with wrappings G, A and B. With other foils, the content of WSC ranged from 8.23 to 8.93%. During the subsequent months of storage, the amount of sugars decreased. The largest loss, almost 1%, was recorded for haylage wrapped with foil having microbiological components102631 (G). The smallest fluctuations of sugar content over time were observed with the 8% zinc-based microorganism addition (F). The variance coefficient for the value of the second period was lower compared to the first test period.

The two most important characteristics determining if the haylage is of good quality or not are the dry matter content and the sugars content (Finch *et al*., 2014). The maximum dry matter content of good quality haylage given by Sęk (2002) is 29 - 48%. During the first and second analysis this value was not

Table 1. Selected quality indicators of haylage depending on the type of film used and the length of storage.

Foil type	**Dry matter (%)**		**pH**		**Water soluble carbohydrate (%)**	
Months from bale wrapping	**4**	**12**	**4**	**12**	**4**	**12**
A	42.7	42.4	4.42	4.46	9.53	9.11
B	41.3	-	4.34	-	9.33	-
C	44.1	-	4.28	-	8.71	-
D	45.2	43.4	4.40	4.49	9.82	9.05
E	43.1	42.8	4.36	4.41	8.93	8.51
F	40.2	38.3	4.32	4.38	8.23	8.06
G	41.1	40.4	4.27	4.39	9.64	8.71
Variance	17.6269	18.9081	0.0032	0.0054	3.9714	3.0949

exceeded. Haylage produced using foils with modified recipes showed greater dry matter losses compared to standard foil. At this stage of the study, it is difficult to explain the reasons for these differences. During the first and second analysis, the measured pH of the haylage was within the normal range (pH 4.0 - 5.0). It is, however, dependent on the dry matter content. By comparing the pH of haylage from two periods, none of the samples showed a pH below 4.2. The haylage achieved with the standard foil at the two dates had the highest pH. The high content of WSC in haylage produced by using nanosilver-component foils may indicate a slower development of lactic acid bacteria.

Conclusions

1. Foil containing 3 and 8% microcellulose component was not suitable for bales which are intended for long-term storage.
2. Haylage produced using foils with a modified recipe was characterised by greater dry matter losses compared to haylage produced using standard foil.
3. Haylage bales wrapped in standard foil had the highest pH.
4. The highest concentration of water soluble carbohydrates was characterised by haylage made with the addition of nanosilver particles.

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Watching grass grow: a spatial and geoclimatic analysis of grass growth in Ireland

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Abstract

Farm level differences in the volume of grass production per ha may partially explain differences in farm economic performance in Ireland. The extent to which such differences in grass production are due to geoclimatic, agronomic, or other factors remains unclear. A spatial model that explains the dynamic effects of location on grass growth would offer valuable insight to farmers and agricultural policy makers. Remote sensed enhanced vegetation index (EVI) data is used along with a wide range of pedologic and climatic data for over 90,000 farm locations in Ireland. Cluster analysis is used to organise the data into distinct geoclimatic regions. Annual EVI is regressed on a range of spatially disaggregated geoclimatic variables using random effects models. These models explain up to 73% of the overall variation in vegetation growth and are robust at the national and regional levels. This study demonstrates that agronomic variables significantly influence EVI. This suggests that EVI is valuable proxy for grass production. This paper highlights the wide variations in growing conditions across time and space in Ireland and introduces a method to quantify these variations.

Keywords: grass growth, multivariate analysis, spatial analysis, remote sensing

Introduction

Grass growth is central to Irish agriculture. More than four fifths of Ireland's farmland and more than two fifths of Ireland's land area are made up of grassland (CSO 2012; Eurostat 2012). Despite the importance of grass production to Irish farming, limited quantitative yield data exists at a nationally representative scale. Grass growth models, such as those evaluated by Hurtado-Uria *et al.* (2013), are typically developed in the context of research farms and under ideal conditions, while agronomic typologies lack empirical grass yield data (Collins and Cummins, 1996; Crowley *et al.* (2008)). This study utilises remote-sensed vegetation data, farm location data and pedoclimatic data to link modelling and typology methodologies and explain the differences in grass growth between regions and over time.

Materials and methods

A total number of 90,994 Irish farm locations in 2,919 electoral divisional areas were identified using the 2010 Irish Census of Agriculture and the An Post Geodirectory (CSO, 2012). Monthly enhanced vegetation index (EVI) data was collected at the 250 m^2 resolution for each farm location from 2002 to 2015. Monthly rainfall and temperature data were provided by Met Eireann and were interpolated for each farm location. Soil type and texture data was drawn from the Irish Soil Information System (Creamer, 2008). In order to control for individual farm level error, data was aggregated by electoral district. This also allows for mean district farm size and stocking rate to be included in the analysis since electoral district is the smallest area for which these variables are published. Electoral districts were organised into unique geoclimatic zones by adapting the cluster analysis methodology of Gelasakis *et al.* (2012) and Köbrich *et al.* (2003). Zone 1 included the largely favourable growing regions of the southeast and west midlands. Zone 2 in the centre of the country had the highest EVI overall. Zone 3 was located in the southwestern portion of Ireland and was characterised by higher soil quality. Zone 4 on the extreme west coast of Ireland had the lowest EVI and poorer soils. A random effects model was used to determine the effects of geoclimatic factors on vegetation growth nationally and for each of the four distinct geoclimatic zones.

Results and discussion

Establishing spatially disaggregated measures of grass growth and understanding the location specific relationships between grass and agronomic conditions are critical to improving grass production on Irish farms. This study tests the use of EVI as a proxy for grass production by modelling its dependence on known geoclimatic indicators of growth in 2,919 electoral districts across Ireland. These indicators include monthly temperature and rainfall, soil type and texture, altitude, slope, distance to sea, latitude, stocking rate and mean farm size. Table 1 shows selected results of the annual EVI random effects model at the national level and for each of the four distinct geoclimatic zones. As expected, rainfall and temperature throughout the year had a significant impact on vegetation growth. High March temperatures were positively related with grass growth at the national level but were insignificant for each of the individual geoclimatic zones. The effects of June rainfall also exemplified the disparity between national and regional effects. While higher rainfall in June had a strong negative effect on vegetation growth nationally, effects were less pronounced in the individual zone models. Together, these results highlight the significant differences that exist across the unique agronomic regions of Ireland. Peaty gley soils were associated with the lowest EVI while rendzina soils performed the best nationally and in the geoclimatic zones where they were present. Soil effects, like weather effects were largely as expected and confirm a statistically significant link between EVI and known pedoclimatic indicators of grass growth. The optimal altitude for vegetation growth was estimated at between 145 and 170 m across all models and represented a balance between wetter low lying areas and exposed uplands. Slope was particularly important in Zone 4 in the topographically rugged west coast of Ireland. Farms further south and further from the sea tended to have higher EVI measurements due to additional sunlight hours. Optimal stocking rates were near two livestock units per ha, but the effect was insignificant in Zone 4 where stocking rate varied widely. Average farm size effects suggest that regions with larger farms have higher vegetation growth likely due to better resourced farms.

Table 1. Selected national and zonal coefficients of agroclimatic conditions - effect on annual cumulative enhanced vegetative index (EVI).[1]

Variable	National	Zone 1	Zone 2	Zone 3	Zone 4
Mean temperature in March	670.20***	-205.2*	-65.87	-565.21***	-182.32
Monthly rainfall in June	-12.27***	-5.63***	-9.82***	-0.89	-5.08***
Peaty clay	-6,867.28***	omitted	-4,623.28***	omitted	-11,389.11
Rendzina	3,554.07***	2,817.23***	5,397.61	omitted	-1,029.78
Altitude (m)	70.47***	67.88***	55.46	50.74***	131.57***
Altitude squared	-0.21***	-0.23***	-0.19***	-0.12***	-0.42***
Slope (percent)	-202.86***	-164.65	-154.9	-266.54*	-728.09***
Livestock units per ha (E.D. Mean)	26,210.17***	22,741.55***	31,798.62	19,280.82***	14,251.69***
Livestock units per ha squared	-6,866.07***	-5,632.41***	-9,223.14***	-3,879.22***	-1,147.28
Log of average ha per farm (E.D. Mean)	1,189.45***	2,214.7***	-148.38	1,038.29**	2,078.74***
Constant	40,694.26***	40,271.36***	37,950.92	48,614***	34,498.18***
Observations	2919	697	1,273	564	385
Overall	0.70	0.55	0.65	0.76	0.73
Within	0.64	0.65	0.74	0.64	0.46
Between	0.71	0.52	0.62	0.72	0.75

[1] ***, **, * Denotes that the corresponding coefficients are significant at 1, 5 and 10% level, respectively.

While these effects are unsurprising when compared with existing Irish grass growth models, they underscore the agronomic diversity of Ireland and prove that grass growth can be effectively modelled on a broad spatial scale. The relationship between EVI and agronomic conditions is robust at the national level and across the diverse growing regions of Ireland. This suggests that EVI is a valuable proxy measure for grass growth nationally and locally.

Conclusion

Improved measures of grass growth are an important component of Ireland's strategy to increase production of this low cost, sustainable feedstock. Although on-farm grass growth is difficult to measure, EVI can be a useful proxy to farmers and policymakers for establishing measures of baseline and target grass production. By identifying clusters of similar agroclimatic conditions, 'one size fits all' management and policy solutions can be avoided in favour of techniques which are tailored to specific regions. Future research in this area can relate EVI to dry matter yield and feed energy to track local and national progress towards Ireland's ambitious grass feed production goals.

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Assessment of the state of meadows degradation in Middle Wieprz River Valley PHL060005, eastern Poland

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Keywords: grassland degradation, monitoring, ultralight gyrocopter

Introduction

In many regions, an undesirable phenomenon of leaving grassland without any use has been observed. Abandoning or limiting the use of grassland ecosystems results in their degradation, i.e. reduction of biodiversity, and, in the following stage, secondary succession. The research objective is to verify the hypothesis so that it is possible to assess the extent of degradation (expressed with the Shannon index) of hay, wet and rush meadows and to identify plant communities based on hyperspectral imaging data obtained from a gyrocopter.

Materials and methods

The investigations were carried out on grassland in the Natura 2000 area (Middle Wieprz River Valley, PLH060005), eastern Poland. On-the-ground investigations were conducted with data obtained in hyperspectral analysis and satellite images.

Results and discussion

The values of the spectral image varied depending on the date and type of meadow (plant community). The biggest differences between meadow types were observed within the 765 - 1,290 nm range. The highest spectral image values were found for floristically rich meadows (50%) in the spring and high sedge-beds (53%) in the summer and autumn. In other ranges, particularly within the visible range, the differences were smaller. In the fall, the highest values were observed for wet meadows within the medium infrared range (28%).

Conclusion

A gyrocopter can be used to assess the state of meadow degradation and identify some plant communities, particularly rush and wet meadows.

Acknowledgements

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Associations between cow behaviour at pasture, weather conditions and day length

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Abstract

Pasture grazing of cattle increases economic performance and is regarded as beneficial for cows' health but weather may affect animal behaviour. The study reported here assessed associations between behaviour and weather. Ten spring-calving dairy cows were monitored during spring (63 d), summer (13 d) and autumn (13 d). Cow behaviour was recorded using the noseband sensor and pedometer-based RumiWatchSystem (Itin + Hoch GmbH, Liestal, Switzerland). Weather conditions were measured continuously using an on-farm weather station. When day length exceeded 15 h d^{-1}, cows were observed grazing longer. Rumination time was highest when mean air temperature ranged between 7.5 and 12.5 °C. Rainfall was associated with reduced lying time and increased standing time. Walking time was lower when day length was less than 12 h d^{-1}. No significant associations with wind speed were detected. Overall, moderate associations between weather and behaviour were observed.

Keywords: weather, behaviour, pasture, grazing time, rumination time, linear mixed models

Introduction

Consumers perceive grazing as more natural than indoor systems and grazing animals have greater freedom to express natural behaviours such as exploration (Spooner *et al.*, 2014). Evidence suggests that access to pasture can improve cow health. However, cows' preference for pasture appears to be dependent on weather conditions. Cows have been shown to prefer barns to pasture when temperatures are particularly high (von Keyserlingk *et al.*, 2009). This study assesses the associations between prevailing weather and behaviour of dairy cows at pasture on a fulltime basis.

Materials and methods

The experiment was carried out at Teagasc Moorepark Research Centre, Fermoy, Co. Cork, Ireland across three time periods in 2016. A weather station (less than 1.5 km from the farm) monitored weather during the experiment. Cow behaviour was monitored using the RumiWatchSystem (Itin + Hoch GmbH, Liestal, Switzerland) consisting of a pedometer and a noseband sensor. Eighty nine days of observations occurred during early (63 d), mid (13 d) and late (13 d) lactation. Due to farm management reasons and other ongoing experiments, cows included in the study grazed in groups of 15 animals (early lactation), 105 animals (mid-lactation) and 100 cows (late lactation). Ten cows were observed at any one time. Individual milk yields (kg) were recorded daily at each milking (Dairymaster, Causeway, Co. Kerry, Ireland). Pre-grazing sward height was measured daily with a rising plate meter (diameter 355 mm and 3.2 kg m^{-2}; Jenquip, Fielding, New Zealand).

Statistical analysis was performed using R (R Core Team, 2017). Descriptive statistics and density plots have been used to evaluate distributions of all continuous variables. A linear mixed model for repeated measures ('lme4' package of R; Bates *et al.*, 2008) was built for eight response variables to evaluate the effects of weather, day length and other covariates. Fixed explanatory factors included in initial models were temperature, rainfall, wind-speed and day length. Fixed effects included in the final models were selected based on Akaike Information Criterion (AIC) using a back-fitting procedure (Tremblay and Ransijn, 2015). The model with the lowest AIC was considered the best and final model.

Results and discussion

Due to the non-normal distribution of weather and day length data, values originally recorded on continuous scales have been transformed into three level factors aiming to include at least 100 observations in each factor (Table 1). Five models for five dependent variables were developed (Table 2). Cows grazed longer with longer day length. Grazing time was significantly higher when day length was > 15 h (631.3 ± 14.9 min day^{-1}) compared to 12 - 15 h (585.5 ± 15.2 min day^{-1}; $P = 0.001$) and < 12 h (576.8 ± 17.0 min day^{-1}; $P < 0.001$). Each 1 cm increase in pre-grazing grass height resulted in a reduction of 7.4 min day^{-1} in grazing time ($P = 0.001$).

Grazing time increased 1.45 min day^{-1} for each kg day^{-1} of milk yield ($P = 0.042$). Rumination time was 422.1 ± 14.6, 457.0 ± 15.0 and 419.8 ± 23.3 min day^{-1} in the classes of temperature < 7.5, 7.5 - 12.5 and > 12.5 °C, respectively. Significant differences were found between temperature classes < 7.5 and 7.5 -

Table 1. Descriptive weather statistics, discretization criteria and the number of observations in each level of the resulting factors.

Item	Continuous				Categorical		
	Min	Max	Mean	*SD*	Cut-points	N	%
Temperature (°C)	4.10	19.59	10.53	3.93	< 7.5 °C	189	25.0
					≥ 7.5 °C < 12.5	340	44.9
					≥ 12.5 °C	228	30.1
Rainfall (mm d^{-1})	0.00	21.00	1.40	3.32	< 0.1 mm d^{-1}	388	51.3
					≥ 0.1 mm d^{-1} < 2.5	239	31.6
					≥ 2.5 mm day^{-1}	130	17.2
Wind speed (m s^{-1})	1.07	5.21	2.74	0.98	< 2.0 m s^{-1}	204	26.9
					≥ 2.0 m s^{-1} < 4.0	445	58.8
					≥ 4.0 m s^{-1}	108	14.3
Day length (h)	9.66	16.33	13.92	2.09	< 12 h	137	18.1
					≥ 12 h < 15	310	41.0
					≥ 15 h	310	41.0

Table 2. Descriptive statistics for behaviour outcome variables investigated and corresponding fixed effects retained in final models.

	Grazing time	Rumination time	Lying time	Standing time	Walking time
Mean (min day^{-1})	596.6	488.9	579.5	773.5	89.8
SD (min day^{-1})	77.1	69.5	146.5	135.6	23.7
Rainfall (mm day^{-1})			***	***	
Temperature (°C)		***			
Day length (h)	***				***
Supplementation (kg)		***			
Group dimension			**		***
Pre-grazing grass height	***				
Days in milk (d)		***	***	***	
Milk yield (kg)	*	***			

* $P = < 0.05$, ** $P = < 0.01$, *** $P = < 0.001$; variables assessed but not retained in any of the five final models: wind speed, herbage allowance, parity and breed; time = m day^{-1}.

12.5 °C ($P = 0.014$), and 7.5 - 12.5 °C and > 12.5 °C ($P = 0.030$). Rumination time was not significantly different between the classes < 7.5 and > 12.5 °C.

Concentrate supplementation was associated with significantly reduced rumination time (504.1 ± 10.8 vs 361.8 ± 32.0 min day^{-1}; $P < 0.001$). Rumination increased by 0.75 min day^{-1} for each day of Days in Milk (DIM) ($P < 0.001$) and by 2.58 min day^{-1} for each kg day^{-1} of milk yield ($P < 0.001$). Lying time decreased with increasing rainfall. Cows lay down for significantly longer times on dry days (582.9 ± 19.3 min day^{-1}) than when rainfall was 0.1 - 2.5 mm day^{-1} (536.8 ± 20.1 min day^{-1}; $P = 0.041$) and > 2.5 mm day^{-1} (478.4 ± 24.3 min day^{-1}; $P < 0.001$). A significant difference was also found between the classes of rainfall 0.1 - 2.5 and > 2.5 mm day^{-1} ($P = 0.048$). Lying time was significantly shorter in a big group (473.7 ± 29.9 min) than in a small group (591.7 ± 20.2 min; $P = 0.003$), with a difference of almost 2 h d^{-1}. Lying time also increased with DIM.

In summary, rainfall and day length were both associated with two out of five behaviour measures assessed. Temperature was associated with only one variable, rumination time. No significant effects of wind speed were found. The generally modest effects are likely to be due to the mild weather during the observation periods. This is particularly true of rainfall (daily mean 1.4 mm day^{-1}).

Conclusion

Cow behaviour was associated with weather during the observation periods. Rainfall, in particular, was associated with increased standing time and reduced lying time as well as rumination. This could have implications for production and lameness prevalences.

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Evaluation of a novel grassland monitoring index based on calibrated low-cost UAV imagery

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Abstract

Monitoring quality and quantity of grasslands throughout the growing season is an essential step towards the optimisation of yield. As part of precision agriculture applications, monitoring approaches should provide a near real-time analysis with high spatial and temporal resolution. However, manual measurements with rising plate meters (RPM) and spectroradiometers have a limited spatial coverage, are time consuming and sometimes are not feasible due to terrain or weather. Exploiting the information of red-green-blue (RGB) image data from consumer grade cameras mounted on unmanned aerial vehicles (UAV) can overcome these limitations. Based on these findings a novel index for grassland monitoring was proposed by Bareth *et al*. (2015), the *GrassI*, which combines structural and physiological information. In this study the *GrassI* is evaluated utilising data from the Rengen Grassland Experiment (RGE) in Germany. The good correlation of the *GrassI* with RPM measurements (R^2: > 0.85) indicates a promising alternative monitoring approach.

Keywords: unmanned aerial vehicle, rising plate meter, RGB vegetation indices, monitoring

Introduction

Monitoring quality and quantity of grasslands throughout the growing season is an essential step towards the optimisation of yield. As part of precision agriculture applications, monitoring approaches should provide a near real-time analysis with high spatial and temporal resolution (Schellberg *et al.,* 2008). However, manual measurements with rising plate meters (RPM) and spectroradiometers have a limited spatial coverage, are time consuming, and sometimes are not feasible due to terrain or weather. Exploiting the information of image data from consumer grade cameras mounted on unmanned aerial vehicles (UAV) can overcome these limitations. Two important monitoring parameters can be derived from UAV-based red-green-blue (RGB) image data, sward height and vegetation indices: (1) Sward height from UAV-based imagery is derived from crop surface models and has been shown to have a strong correlation with RPM measurements (Bareth *et al.,* 2015; Lussem *et al.,* 2017). (2) Vegetation indices from UAV-based RGB image data seem to be more robust to subtle changes in greenness and show less saturation effects with increasing biomass compared to vegetation indices such as the NDVI (Bendig *et al.,* 2015). Based on these findings a novel index for grassland monitoring was proposed by Bareth *et al.* (2015), the *GrassI*, which combines the above mentioned parameters. The idea behind the *GrassI* is the combination of structural and physiological information to better estimate plant growth and ultimately yield. In early growing stages the *GrassI* is dominated by the reflectance information of the red-green-blue vegetation index (RGBVI). The saturation effect of the VI is corrected by the UAV-based sward height (Bareth *et al.,* 2015). The objective of this study is to evaluate the *GrassI* as a possible alternative for RPM measurements.

Materials and methods

The study utilizes data collected on the Rengen Grassland Experiment (RGE). The RGE is a longterm experiment established in 1941 in the Eifel mountain region in Germany and comprises five treatments (Ca, CaN, CaNP, $CaNPK_2O$, $CaNPK_2SO_4$) with ten replicates (plot size 3 × 5 m) and two cuts per year (Chytry *et al.,* 2009). For this study five sampling dates of the first growth in 2014 (mid-April to mid-June) of 25 plots (five replicates per treatment) were selected for investigation. Ten evenly distributed RPM measurements were taken per plot on each sampling date and averaged per plot. Ground Control Points for georeferencing were evenly distributed on the field and measured with a real-time kinematic positioning system. Image data was collected with a low-cost UAV (DJI Phantom 2) equipped with a Canon PowerShot 110 camera (~150 images per sampling date). For each sampling date a crop surface model (CSM) was computed to derive sward height (SH) per plot (for details see Bendig *et al.,* 2015). To calculate the RGBVI per pixel (Equation 1) an overview image (~ 40 m above ground level) for each sampling date was taken of the 25 investigated plots. These images were approximated to surface reflectance by the empirical line method (Smith and Milton, 1999) using four reference panels in different shades of grey. The *GrassI* is calculated according to Equation (2).

$$\text{RGBVI} = (R_G)^2 - (R_B{*}R_R) / (R_G)^2 + (R_B{*}R_R) \tag{1}$$

$$\textit{GrassI} = \text{SH} + \text{RGBVI} \tag{2}$$

with R = Reflectance in % of the red, green and blue channel (R-, G-, B-subscript characters, respectively) and SH = sward height from CSM. The main aim of this study is to compare the *GrassI* to RPM measurements. Therefore, the dataset was split into two randomly selected subsets for calibration (n= 75) and validation (n = 50). Regression analysis was performed to test the relationship between RPM measurements and *GrassI*. An exponential regression model provided the best fit for the calibration dataset (Figure 1) and was selected for modelling the RPM measurements to validate the approach (Figure 2). Coefficient of determination (R^2) and root mean squared error (RMSE) were calculated. Analysis was conducted in the statistical computation software R (R Core Team 2016).

Results and discussion

The spread of data points from the *GrassI* and RPM measurements of the calibration subset is shown in Figure 1. Increasing heterogeneity of the sward per plot towards later sampling dates is indicated by an increasing standard deviation of both *GrassI* and RPM.

Collecting overview images of the area of interest instead of image-mosaics partly eliminated the problem of varying incident light which affects calculation of vegetation indices from aerial imagery, as discussed by Bendig *et al.* (2015). The RGBVI-part of the *GrassI* seem to provide valuable information for plots where the sward is either relatively short in early growing stages or is lodging in later growing stages. In case of lodging, taking only the SH from CSMs into account would underestimate the actual sward height. Validation of the exponential regression model based on the calibration dataset with the independent subset shows a strong correlation between measured and modelled RPM sward height (R^2 = 0.89) with an RMSE of 3.2 cm. Therefore, the presented approach could serve as an alternative way to monitor forage yield. Furthermore, the advantage of using UAV-based RGB imagery is the high spatial (centimetre-range) and temporal resolution on which fields can be assessed compared to manual RPM measurements.

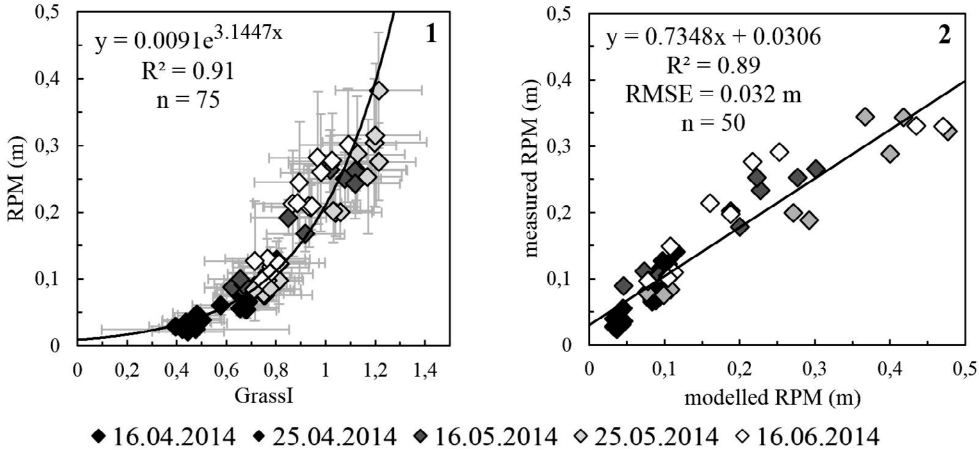

Figure 1. (left). *GrassI* vs rising plate meter measurements for calibration subset. Horizontal error bars indicate standard deviation of *GrassI*, vertical error bars indicate standard deviation of RPM ($P < 0.001$). Figure 2 (right). Relationship of measured vs modelled RPM sward heights of the validation subset ($P < 0.001$).

Conclusion

Non-destructive measurements of sward height in combination with vegetation indices from the visible spectrum based on UAV imagery can aid decision-making regarding grazing management or nutrient extraction on farms. The high spatial resolution can be beneficial in precision farming applications for sustainable grassland management. However, the *GrassI* needs to be further validated with datasets covering multiple years and sites to better investigate results of combined structural and physiological plant components.

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The use of radar satellite images for the detection of cutting frequency of grassland

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Abstract

The European Earth Observation Programme 'Copernicus' provides vast amounts of spatio-temporal data collected by a set of dedicated satellites (Sentinel). This open and free data can be used for operational monitoring of the environment, for example, for the observation of grassland and agricultural fields. An automated satellite and ground data processing method to detect cutting events and thereby, to estimate grassland yields has been developed. It will incorporate big data from space but also data on climate, soil, plant and field borders. The cutting frequency and yields gained by this method are essential for optimising the use of grassland and for yield adjusted fertilisation. We present the comparison of detected cutting frequencies of grassland from three regions. The detection results showed that regional differences are observed by the satellite data. Furthermore, they were able to reflect the variation in grassland management mainly governed by different regional climate and orography. These cutting frequencies are essential for the next step, that is, the calculation of grassland yields based on a phenological grassland model.

Keywords: radar, change detection, Sentinel-1, grassland, satellite, cutting frequency

Introduction

Grassland occupies a large proportion of utilised agricultural area and contributes significantly to milk and meat production. In Bavaria (Germany) grassland covers more than 34% of the farmland (StMELF, 2016). Despite its importance, current and comprehensive data on grassland yields and cutting frequencies are lacking; available data are only based on estimates and expert experience. Model approaches for the assessment of grassland yields take cutting dates and frequency into account, as well as parameters like climate, soil, plant composition and fertilisation (Hermann *et al.*, 2005). Therefore, a time and cost effective method for detection of grassland cutting times would not only improve estimation of grassland yields and allow adjusted application of fertiliser, but it would also be an instrument for nature conservation and policy consultation.

Remote sensing techniques allow the monitoring of the earth´s surface and its changes. The European Earth Observation and Monitoring Programme Copernicus of the European Space Agency (ESA) using Sentinel satellites offers freely and openly accessible data suitable for scientific applications. Spatial and temporal high-resolution Sentinel-1 radar data allow detection of single cutting events based on changes of the radar backscatter of matured and harvested grassland (Grant *et al.*, 2015). The aim of this study is to record regional cutting frequencies by adding up single cutting events. Regional differences in usage intensity should be revealed with time series of radar images.

Materials and methods

Three regions with different climatic and agricultural conditions, situated in Bavaria (Germany), were selected for the project. The Allgaeu is a predestined area for dairy farming with highly productive and intensively used grasslands. In contrast, in Middle Franconia plant growth is limited by water availability and dry periods during the growing season. The Bavarian Forest is characterised by lower temperatures in high altitudes and orographic impacts in hillside locations. Therefore, grassland yields in Middle

Franconia and the Bavarian Forest only allow a less intensive usage than in the Allgaeu (Table 1). All cutting times of selected grassland plots in the regions were monitored during the vegetation period of April to November 2016.

A series of radar images acquired by satellite Sentinel-1 was used, which were VV/VH polarized with X-band data acquired in IW mode. Images with the same acquisition geometry and time intervals of six or 12 days were evaluated. Due to unavailability of Sentinel-1A satellite in summer 2016, single image time gaps were up to 36 days long. SLC radar data were radiometrically calibrated in order to make specific comparisons possible. The corrected amplitude data were terrain corrected and georeferenced using the Range Doppler orthorectification method. Multi-looking algorithms and an adaptive Frost filter (window size 5 × 5) ensured the reduction of the speckle effect. After image processing was performed with ESA's Sentinel Application Platform software (SNAP), satellite data was transformed to the logarithmic scale (dB), exported as GeoTiffs and analysed with R (R Core Team, 2016) and the packages *raster* (Hijmans, 2016) and *rgdal* (Bivand *et al.*, 2017). The strength of the radar returns, and thereby, the grey values of the images were influenced by roughness and wetness of the surface. Changes of the radar return intensity between matured and harvested state of a grassland plot indicated a cutting event. For each selected grassland plot, single cutting events detected by satellite imagery, with a minimum time lag of 21 days, were counted and compared to *in situ* measurements. Comparisons between the study areas were performed with Welch Two Sample t-test, with $P < 0.05$ being considered as significant.

Results and discussion

At individual plot level, analyses showed a 50% matching rate between annual cutting frequency in 2016 detected with Sentinel-1 data and *in situ* measurements. Errors were distributed equally across all cutting frequencies. Due to the large time gaps caused by the Sentinel-1 system failure, alterations in the grey values of radar images did not show the expected clear behaviour during the affected regrowths. Therefore, two subsequent satellite images could display a similar state of plant cover, even when the plot was cut in the period between the images. If deviations by one cut more or less were tolerated, the matching rate increased to 93.5%. In the remaining vegetation period, time intervals were accordingly short, so most cuts were well captured.

The mean cutting frequencies for each region detected with radar images showed very few differences to the cutting frequencies from *in situ* measurements (Table 2). Cutting frequencies for every study area detected with Sentinel-1 differed significantly from each other ($P < 0.02$). The more intensive use of grassland and better climatic conditions in the Allgaeu area resulted in one cut more than in Middle Franconia and in the Bavarian Forest. So, regional specific cutting frequencies and hence, differences in the usage intensity are detectable with this method and can be extended to larger areas. Errors at individual plot level averaged out and the statistical accuracy of prediction was given. The performance of the method with lower cutting frequencies (less than three) still needs to be tested, because in this study the small amount of extensively used grassland sites did not allow for reliable statements. In Allgaeu and Bavarian Forest areas, standard deviation of the *in situ* cutting frequencies was relatively small, but with

Table 1. Climate data (2004 - 2016, data source: AgrarMeteorologie) and relevant parameters of the study areas.

	Allgaeu	Middle Franconia	Bavarian Forest
Weather station	Spitalhof/Kempten	Triesdorf	Steinach
Mean annual rainfall	1,129 mm	665 mm	760 mm
Annual average temperature	8.2 °C	8.7 °C	8.8 °C
Number of plots	88	52	75
Sentinel-1 relative orbit	168	66	95

Sentinel-1 a greater spread appeared. In contrast, in Middle Franconia the reverse was true (Table 2). In that area a part of the observed plots was in nature protection areas, where a less intensive usage intensity is prescribed by law.

Table 2. Mean cutting frequencies detected with Sentinel-1 radar images and *in situ* measurements and their standard deviations for the three study areas.

	Mean		Standard deviation	
	In situ	Sentinel-1	*In situ*	Sentinel-1
Allgaeu	5.02	5.06	0.45	0.76
Middle Franconia	3.73	3.75	0.93	0.81
Bavarian Forest	4.16	4.05	0.49	0.63

Conclusion

The presented method provides sufficiently good results for regional issues like quantifying grassland use intensities of communities or counties. Applications at single plot level require a better reliability. Therefore, a higher temporal resolution than that provided in 2016 is necessary. Sentinel-1B data was available from September 2016. With a second similar satellite, the time interval decreased to approximately six days in 2017, so the temporal coverage allows a higher accuracy in detecting single cutting events.

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Grasshopper: micro-sonic sensor technology enables enhanced height measurement by a Rising Plate Meter

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Keywords: grassland, rising plate meter, precision agriculture, grass height, geo-tag

Introduction

Globally, the Rising Plate Meter (RPM) is utilised as a grassland management tool to measure compressed sward height (CSH) to estimate herbage mass (HM). A RPM utilising a micro-sonic sensor and digital data capture *via* a Bluetooth communications link to a smart device application has been developed, i.e. the Grasshopper. Here we examine the accuracy of height measurement by the Grasshopper compared to a standard cumulative ratchet counter RPM.

Materials and methods

Height measurements of 31 individual PVC pipes (110 mm diameter) of known heights (25 - 178 mm) were taken with a Grasshopper MK4 (True North Technologies, Ireland) and a Jenquip RPM (Filip's Manual Folding Plate Meter, New Zealand). Each pipe was measured 30 times by each of the RPMs. Accuracy was examined as the difference between the true pipe height and the heights recorded by the RPMs. This difference was converted to proportional error and analysed using beta regression ('betareg' package in R v3.4.3 2017). This model incorporated both the effects of 'RPM' and 'pipe height', and their interaction. Data were transformed to reduce extremes (0's) prior to analyses (Smithson and Verkuilen, 2006): $y_t = (y(n - 1) + 0.5 / n$ where y_t is the transformed output and n is the sample size.

Results and discussion

The Grasshopper measured the pipe heights more accurately than the Jenquip ($z = 40.42$, $P < 0.001$). The cumulative ratchet counter RPM underestimated height by 7.68 ± 0.06 mm (mean ± SE). Alternatively, the micro-sonic sensor RPM overestimated height by 0.18 ± 0.08 mm. The 'RPM × pipe height' effect was significant ($z = -16.60$, $P < 0.001$), reflecting greater differences in accuracy between the RPMs at lower pipe heights. In addition, the Jenquip's cumulative ratchet counter design facilitated measurement in increments of 5 mm, while the Grasshopper allowed 1 mm increments of measurement.

Conclusion

The Grasshopper micro-sonic sensor captured fixed height measurements more accurately than a cumulative ratchet counter RPM.

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The development of an in-field livestock performance hub for grazing cattle

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Abstract

Constraints in infrastructure, capital, labour and lack of appreciation of the importance of regular performance monitoring potentially contribute to the low levels of animal performance recording during the grazing season. Commonly during the grazing season, cattle are supplemented with concentrate and/or mineral/vitamins, however delivery of the supplement is on a group basis potentially leading to over or under supply to the individual animal. The objectives of this project were to design and develop a mobile in-field portable livestock performance monitoring and precision feeding hub. Key requirements and technical drawings were developed by the design team leading to the manufacture of the prototype. Intensive testing with dairy heifers (three - 23 months of age) enabled the refinement of the design and functionality. A second prototype, complete with low ground pressure tyres, wireless communication system to the farm office and inbuilt field equipment storage is currently undergoing final stage testing at AFBI. Remote monitoring of performance and precise delivery of supplements to the individual grazing animal is now possible. This new equipment will provide the capability for a wide range of studies into the interactions between livestock, grassland, supplementation and weather leading to the design of more efficient grassland production systems.

Keywords: precision, grazing, livestock, nutrition, performance

Introduction

Precision monitoring of livestock performance and delivery of nutrition on an individual animal basis has become commonplace within many indoor systems. During lactation, concentration supplementation of dairy cow diets is often linked to the individual animal's milk output, stage of lactation and body weight and condition score. Individual animal based approaches are less common with drystock, with supplementation commonly on a group basis, therefore, requiring the producer to group animals with similar nutritional requirements. Not only can grouping add logistical complexity and be limited by the design of the housing, but also impose the need for regular regrouping to ensure the individual animals nutritional needs are met as they grow.

Performance monitoring, often inbuilt within dairy parlour systems, is less regular or non-existent within drystock systems, with visual assessment by the producer the most common method of accessing animal performance. Within the grazing environment of non-lactating dairy animals, if practiced at all, measuring live weight performance can be difficult and labour intensive with weight assessment commonly limited to when animals are housed, sold or undergoing veterinary/anthelmintic treatment. Precision supplementation of grazing animals with energy, protein, minerals, vitamins formulated for each animal's individual needs within the grazing group has not been possible. The ability to strategically supplement animals due to real time data on weather, grazing or soil conditions has also not been possible.

With the development of solar, EID, precision feeding and communication technologies, the objectives of the project were to develop a mobile livestock performance and precision nutrition hub for use by grazing cattle.

Materials and methods

A list of key functional requirements for the hub was circulated to livestock unit managers and research scientists within AFBI to consider. Key requirements included:

- ability to be towed by a small tractor or rough terrain vehicle with minimal soil compaction;
- inclusion of an in-built power supply charged by solar technology;
- ability to electronically identify individual livestock via Full or Half Duplex Ear Tags;
- ability to deliver and record individual animal water intake;
- ability to deliver and record concentrate offered and refused during individual meals and summarise data in user defined time periods; this includes the ability to feed up to four different concentrate types (meal or pellets) either isolated or blended;
- ability to record individual animal live weight at each visit;
- on-board touch screen computer system which could be linked to in-field and on-animal sensors as well as on-board webcam and electronic weather station;
- ability to deliver and record intake of additives, minerals, vitamins, etc. through a high precision micro dispenser;
- adjust in size to accommodate cattle ranging from 75-800 kg in weight with automatic backing gate to prevent bullying;
- two-way transfer of data and feed plans from hub to central computer which could be up to 5 km away.

Discussions with the engineering and manufacturing partner regarding materials, functional requirements, energy consumption and working environment resulted in technical drawings and 3D animations. Working, full scale prototype equipment were designed, manufactured and delivered for testing on the research farm platform.

Results and discussion

During the initial testing, the prototype pictured in Figure 1 correctly identified and weighed individual animals. However, the accuracy of the feed dispensing/weigh back system was not consistent with small amounts of feed spilled. During this testing phase the additional modifications required included reducing

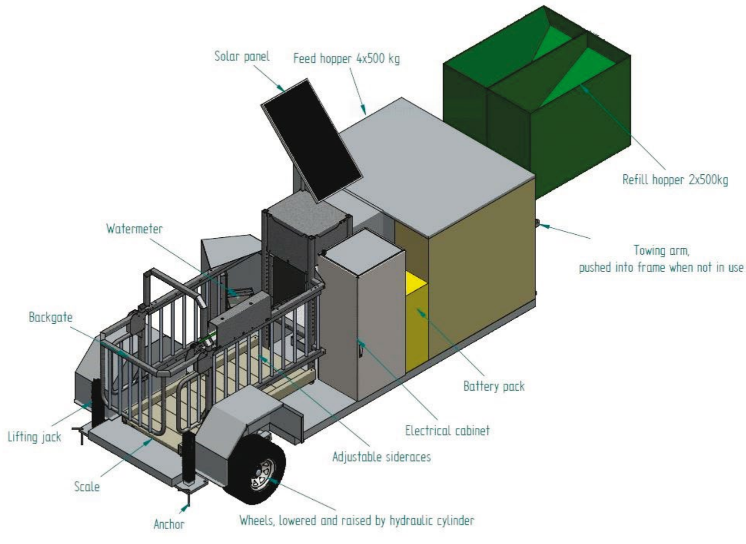

Figure 1. Original Prototype mobile livestock performance and precision nutrition hub.

the ground pressure during field transport, increasing the robustness and speed of the automatic backing gate, protecting the feed manger from being contaminated by water spillage from the drinking bowl, reshaped feed hoppers, modifications to the software control system and lengthening/strengthening of the drawbar. The second prototype hub is pictured in Figure 2.

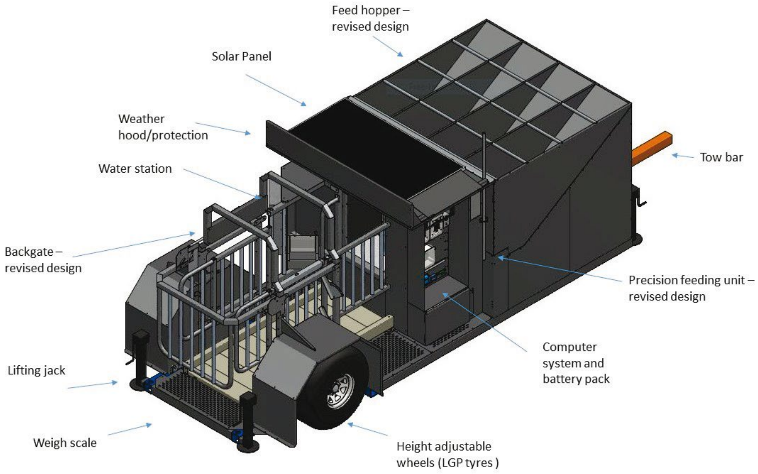

Figure 2. Second prototype mobile livestock performance and precision nutrition hub.

During proof of concept studies in the field, with the hub as the only source of water and supplements, the majority of animals voluntarily entered the hub and received their allocated concentrate ration. Future inclusion of an on-board weather recording station, camera and animal mounted activity sensors downloaded via the hub will enable further detailed investigation of animal behaviour.

Conclusion

Accurate and regular measurement of performance enables more informed management and therefore, improved animal/enterprise performance. The development of the mobile livestock performance and precision nutrition hub opens up the possibility of precision and tailored nutrition plans for the individual animal within a grazing herd. Future research projects will explore and develop strategies on how to best exploit this technology taking into account animal behaviour, grass quality/availability, soil conditions and current/expected weather.

Development of an optimum grass measurement strategy for precision grassland management

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Abstract

The rising plate meter (RPM) is a tool for predicting herbage mass (HM) based on average compressed sward height (CSH) recorded within pasture-based livestock paddocks. Sampling resolution and distribution are primary parameters in determining the spatial heterogeneity of HM, which is essential for correct allocation of sufficient HM to the herd, which in turn optimises pasture utilisation. Currently, there is no definitive sampling protocol for the RPM. The objective of this study was to determine a sampling intensity that optimises the combination of both accuracy and labour efficiency. To best estimate mean CSH, blanket sampling (n = 624) was conducted on controlled trial plots (area = 96 m^2) using an RPM, on a weekly basis, over an entire grazing season. Sward heterogeneity was calculated as the coefficient of variation (CV) of CSH. Retrospective analysis was conducted to simulate the effect of various reduced sampling intensities on estimated mean CSHs. Analysis of the data indicated that mean CSH can be estimated to within 5% error of the mean using a minimum of eight samples per plot. CV peaked in early spring and in non-fertilised plots indicating the necessity for dynamic optimum sampling intensities. The initial findings from this study indicate the requirement for a dynamic sampling strategy that is dependent on grass growth factors including season and level of fertilisation.

Keywords: rising plate meter, sward heterogeneity, precision grazing, sampling strategy

Introduction

European pasture-based livestock agriculture has declined in recent decades compared to concentrate-based feeding systems. This may be a consequence of the reduced feeding efficiency associated with grazing (Huyghe *et al.,* 2014). Shalloo *et al.* (2005) have shown that grazing systems have the potential to produce high outputs at lower costs, but are hindered by the reduced controllability of grass availability and quality. Accurate estimation of herbage mass (HM) is essential in optimising grass utilisation and increasing profit margins (French *et al.,* 2015). Measuring compressed sward height (CSH) using the rising plate meter (RPM) is considered to be one of the most effective means of estimating HM (Sanderson *et al.,* 2001; O'Donovan *et al.,* 2002). At present there is no definitive sampling protocol to estimate HM or to capture the spatial and temporal heterogeneity of grazed swards. While it may be assumed that increasing the sample distribution per paddock will increase accuracy, this further increases the time and cost of sampling. Hutchinson *et al.* (2016) prototyped sampling guidelines based on the operator's desired level of accuracy. Jordan *et al.* (2003) outlined how a blanket sampling scheme could be utilised to undertake retrospective analysis to determine an optimum sampling rate and pattern for HM prediction. The objective of this study was to investigate potential optimum sampling strategies for the RPM by blanket sampling pastures and employing retrospective analysis to systematically refine the required number of samples to efficiently estimate CSH.

Materials and methods

Blanket CSH samples (n = 16,484) were recorded on perennial ryegrass cultivar trial plots at Moorepark over 27 weeks throughout the growing season (between March and October 2017). Four alternating groups of 16 individual plots (5 × 1.2 m), out of a total 64, were measured and cut on a weekly basis; this allowed for a 28 day regrowth period between cuttings. The experimental design of the plots consisted of four treatment subgroups (N0, N1, N2, N3) in a randomised block design, depending on four incremental rates of nitrogen (N) fertiliser applied on a weekly basis (N0 = 0 g, N1 = 13.33 g, N2 = 27.5 g, N3 = 52.5 g,). Sampling was conducted using the Grasshopper RPM (True North Technologies Ltd.) and a purpose built grass sampling rig (Fermoy Engineering Services Ltd.). The portable rig was designed with an internal grid, comprising of 350 mm × 350 mm sections, divided into 13 strata, which enabled the maximum practical number of samples (n = 39) to be taken and geo-referenced on each plot with minimum practical error and bias. Blanket sampling (n = 624) was conducted to get the best estimate of the mean CSH per plot. All of the CSH data from each of the 16 plots recorded per sampling date was combined to simulate a small paddock (96 m^2), with prominent sward heterogeneity as a result of the varying N levels. Statistical analysis was undertaken using Microsoft Excel (2010). A randomisation function was employed to randomly remove samples from each rig strata incrementally, to simulate random stratified sampling strategies of depreciating sampling rates, as recommended in Webster and Lark (2012) and Hutchinson *et al.* (2016). Each random sample selection was generated 30 times to determine the optimum sample number for corresponding levels of standard error (SE) of predicted average CSH. To simulate the effect that reducing the sampling rate would have on the percentage error of estimated mean CSH, sampling rates were retrospectively reduced incrementally, by randomly removing samples from each strata of the sampling rig. This resulted in eight simulated sampling rates (n = 624, 416, 208, 96, 64, 16, 4, 1) per paddock. Sward heterogeneity was defined by the CV of CSH, as in Jordan *et al.* (2003). Descriptive statistics and nonparametric significance testing was carried out on CV data using IBM SPSS Statistics 24 (2016).

Results and discussion

Sward heterogeneity, in terms of CV of CSH was observed to be significantly higher (19.4%) than average ($P < 0.001$) in early to mid-spring (Table 1). Average CV across the entire season was significantly higher (18.5%) ($P < 0.001$) for treatment group (N0), where no N was applied (Table 1). The high CV observed across all N treatments in spring may be a consequence of the interference in plate height readings caused by weeds, which are more prevalent at the typically lower grass heights recorded early in the growing season. This phenomenon is further compounded by the higher average annual CV observed in the N0 treatment group, as the lack of N applied in this group allowed weeds and white clover to persist in the sward, and this was observed throughout the year. These findings indicate the scope for devising a versatile sampling strategy that could be varied depending on growth factors such as season and N fertilisation rate. The SE analysis presented in Figure 1, illustrates how the optimum sampling rate for the combined plot area could be reduced from 624 to eight to estimate mean CSH within ± 5% SE, resulting in a considerable reduction in labour cost and time. The author's note that the findings of this trail are not directly scalable to full size grazed paddocks, as sward variation resulting from animal grazing behaviour and excretion are not accounted for. Furthermore, the variation in CSH resulting from the four different controlled N treatments is not representative of typically fertilised grazed paddocks. The findings of this study are preliminary and will be used to inform and design a full-scale study on grazed paddocks over a number of growing seasons.

Table 1. Average coefficients of variation (CV) per season (for every three weeks of sampling) and annual CV averages per N treatment group.

Average CV (%)								
Season								
Early Spring	**Late Spring**	**Early Sum**	**Mid Sum 1**	**Mid Sum 2**	**Late Sum**	**Early Aut**	**Mid Aut**	**Oct**
19.383	15.007	15.717	14.681	15.123	16.601	16.375	14.679	15.518
Treatment group								
N0		**N1**		**N2**		**N3**		**Mean**
18.502		15.252		15.056		15.347		16.058

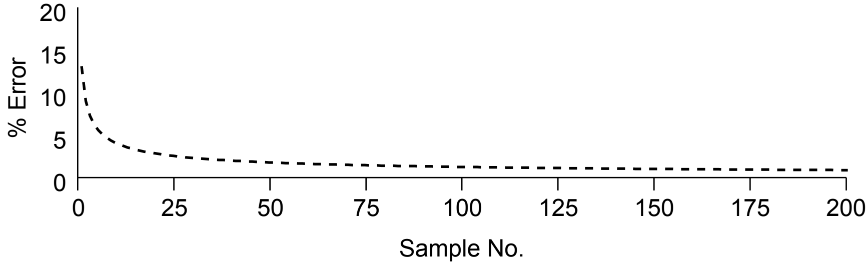

Figure 1. Simulated reduced sample rates plotted against standard error of mean CSH estimates, averaged across data collected for all 27 weeks.

Conclusion

The findings from this research indicate the requirement for a dynamic sampling strategy, incorporating an optimum sampling rate that is dependent on the level of estimated sward variation, which is influenced by growth rate factors such as seasonality and fertilisation. The data generated will be further interrogated to identify various optimum sampling patterns that could be integrated into this strategy. The experimental concept presented in this paper will be scaled up in years 2 and 3 of this study onto grazed plots to examine annual, seasonal and grazing effects on sward heterogeneity.

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A national methodology to quantify the grass credentials of Irish dairy farms

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Abstract

Consumer interest in purchasing milk based on the cow's diet and time spent grazing is growing. This research aims to address these questions by developing a method to regularly quantify the amount of grass in the diet of dairy cows at a national level. The method included the development of a model and the expansion of an existing Irish farm accountancy survey to collect extra data required to estimate cow forage intakes (e.g. turnout and housing dates). The survey was carried out on 275 - 318 nationally representative Irish dairy farms over a three year period. Annual cow feed intakes were calculated to meet net energy requirements for production, maintenance, pregnancy, growth and live weight change. The results showed that grass silage and grazed grass combined accounted for 95% of the cows' diet as fed. Grazed grass comprised 75% of the cow's diet as fed (60% on a DM basis). Our dietary results were in line with previous international research estimates for grazing dairy cows. The method we developed can be applied in countries with similar data collection systems. These grass metrics enable consumers to become more informed about the origin of their food.

Keywords: milk, dairy, pasture, grass, forage, cow

Introduction

The grazing of grass by cows is perceived by most consumers to be animal friendly and an environmentally sustainable method of milk production (Heerwagen *et al.*, 2013). Many research studies support these opinions showing that the grazing system performs better than indoor systems in terms of animal welfare and the environment (e.g. Olmos *et al.*, 2009). The growing consumer interest in the production of milk has led to greater payments to milk suppliers in some regions, e.g. when cows get access to grass for a minimum period (Elgersma, 2015). This satisfies current market demands but provides very little quantitative information on the proportion of a cow's diet represented by grass and may not actually be advantageous from an environmental or animal welfare viewpoint. Consumers are becoming more interested in the actual diet of the cow and are increasingly requesting information on the typical quantities of fresh forage and grazed grass that a dairy cow consumes. The objective of this study was to develop a methodology that can quantify regularly the annual amounts of forage and grass in the diet of dairy cows at a regional or national level.

Materials and methods

The diets of dairy cows were estimated with the Irish national farm survey (NFS, Hennessy and Moran, 2016). The survey was carried out on 275 - 318 specialist dairy farms from 2013 to 2015. The dairy farms surveyed were assigned weighting factors according to their utilisable agricultural area. The weighted results of the survey were representative of the national population, which was typically 16,000 specialist dairy farms. The survey was expanded to collect technical data such as housing and turnout dates, monthly cow concentrate feeding rate, type of forage(s) conserved, milk production and milk composition. Data necessary to compute the diet of animals (e.g. body weight change (BWC)) that could not be collected via surveys was obtained from national publications or through industry consultation.

All dairy farms surveyed were operating grazing systems. Cows were usually left out to pasture in spring after calving. Generally, calved cows remained on pasture until late autumn or early winter. When grass growth exceeded herd feed demand in summer, surplus grass was harvested and fed to cows indoors from early winter to spring. Concentrate feeds were typically offered to cows when grass growth was insufficient to meet herd feed requirements. Concentrate feedstuffs were multiplied by a typical concentrate net energy (NE) coefficient based on research by O'Mara (1996) to estimate NE provided by same, on a monthly basis. The NE from concentrate was subtracted from cows' total NE requirement to estimate the NE provided by forage per month. The total NE requirements for cow maintenance, activity, milk production, pregnancy, BWC and growth were estimated using livestock NE requirement equations from O'Mara (1996).

The proportion of NE that came from pasture monthly was estimated by relating turnout and housing dates to the total NE provided by forage monthly. Net energy provided by conserved forage was estimated as the difference between NE provided from forage and grazed grass. Forage intakes were computed by dividing the NE provided by a forage by its NE value kg^{-1} DM or as fed. The latter was obtained from O'Mara (1996). Grazed grass intakes were estimated as a proportion of a dairy cow's annual, as fed or DM diet. Both were related to the length of the grazing season using the correlation and regression analyses procedures of the statistical analysis systems software package (SAS).

Results and discussion

The total intake of dairy cows as fed increased from an average of 22.7 t cow^{-1} in 2013 to 24.8 t cow^{-1} in 2015 (Table 1). In terms of DM, cows' average annual total intake increased from 4.8 to 5.0 t cow^{-1} over the three years. The majority of Irish cows' average annual diet came from grass. Grass comprised 93 to 95% of the average annual cow diet as fed or 77 to 82% as DM. Grazed grass was the main component of dairy cows grass diets contributing on average 74 to 77% of the average annual cow diet as fed (57 to 63% as DM). Grass silage was the next largest component of the average annual cow diet as fed. This feed was also the second largest consumed by cows on a DM basis (20 to 21%) in 2014 and 2015 followed by concentrate (16 to 17%). In 2013, concentrate was a slightly larger component of the average annual cow DM diet (21% concentrate compared to 20% grass silage).There were strong positive correlations across the year assessed between the length of the grazing season and the proportion of grazed grass in cows' annual as fed diet (r = 0.86 to 0.92; P < 0.001) and DM diet (r = 0.79 to 0.84; P < 0.001). There was a linear relationship between the length of the grazing season and the proportion of pasture in the cow diet for each year evaluated. The fitted relationship was better as fed diet for each year e.g. the 2013 as fed R^2 was 0.85 compared to an R^2 of 0.71 for the DM diet.

We compared our annual cow feed intake estimates to the studies of Vance *et al.* (2012), Patton *et al.* (2016) and Macdonald *et al.* (2001), where cows normally had access to pasture from spring until winter. These studies reported average annual cow feed intakes ranging from 4.4 to 4.8 t cow^{-1}. Our results were within this range and very similar to Vance *et al.* (2012) and Macdonald *et al.* (2001), but generally higher than Patton *et al.* (2016). However, the average milk solids yield (403 - 436 kg cow^{-1}) was higher in this

Table 1. Typical cow diets as fed (mean ± standard deviation) on the Irish national farm survey's specialist dairy farms.

Item	2013	2014	2015	Average 2013-2015
Number of farms	275	318	314	302 (907[1])
Total intake, t fresh matter (FM) cow^{-1}	22.7 ± 2.2	23.7 ± 2.3	24.8 ± 2.5	23.7 ± 2.4
Grass[2], % FM	93.4 ± 3.6	94.9 ± 3.4	95.3 ± 3.0	94.5 ± 3.3

[1] Total farm years.

[2] Grass included grazed grass and grass silage.

study than Patton *et al.* (2016). This is a key factor in determining cow intake and partly explained the difference in forage estimates. Additionally, assumption regarding cow body weight and the chemical composition of forage potentially may explain some of the differences between studies. The proportion of the grazed grass in the typical cow DM diet was also within the range of study estimates and very similar to Patton *et al.* (2016). Our comparison with previous research systems provides solid validation that Irish dairy farms are very reliant on grass, especially grazed grass for a large proportion of their diet. It was only possible to compare our estimates of the quantity or proportion of grass in the diet of dairy cows to model or research farms, because few, if any, have estimated grazing cow diets on a countrywide scale. Based on our experience it should be possible to repeat our approach to estimating typical cow diets where representative regional detailed or national farm information is collected irrespective of country.

Conclusion

A valid method to estimate typical cow diets on a countrywide scale was developed. The study highlights that the proportion of grazed grass in a cow's diet is a useful indicator of the length of the grazing season. This method can provide interested dairy consumers with better information on the contribution of grazed grass to a cow's diet.

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Performance of grass varieties in terms of dry matter production on commercial Irish grassland farms

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Abstract

Conventionally, perennial ryegrass evaluations are conducted under simulated grazing studies to identify varieties with the best phenotypic performance. But ultimately varietal performance needs to be quantified in 'real life' situations. The objective of this study was to evaluate the phenotypic performance of a range of perennial ryegrass varieties on commercial farms. Monocultures of 11 Irish National Recommended List perennial ryegrass varieties were sown on 79 commercial farms throughout Ireland, where performance was evaluated over a four year period from 2013 to 2016, inclusive. A linear mixed model was used to test variety effects on grassland performance characteristics. There was a significant (P < 0.001) effect of variety on total and grazing DM yield. Results from this study show that on-farm evaluation is effective in identifying suitable varieties for intensive grazing systems.

Keywords: monocultures, yield, variety, on-farm assessment, DM (dry matter), phenotypic performance

Introduction

Grass evaluation programmes capable of identifying superior commercial grazing varieties are essential to the success of ruminant production in Ireland. Irish producers have the potential to grow between 12 and 16 t ha^{-1} of grass DM annually. Increasing grass growth and utilisation at farm level is imperative for Irish grassland farmers. With increased market volatility for milk, beef and inputs, such as fertiliser and concentrates, enterprises profitability will be dependent on increasing the proportion of grazed grass in the animals' diet. An evaluation process to identify and promote the use of new varieties with improved on-farm performance in the areas of production, persistence and quality is necessary due to the economic importance of ruminant grazing systems. Since the introduction of Recommended List evaluations to Ireland, the grassland demands of farmers have changed. The question remains whether current evaluations provide breeders with adequate selection criteria and feedback to develop new grass varieties which are akin to the needs of grassland farmers. To overcome the limitations of simulated grazing studies and identify superior grass genotypes suited to grazing systems, there is a need to establish trials which better simulate 'commercial' farm conditions for longer periods than current evaluation protocols. On-farm evaluation has the ability to influence and redirect the breeding of the next generation of grass varieties. The objective of the current study was to develop a large on-farm phenotyping strategy which would evaluate the performance of grass varieties within an intensive grazing regime in southern Ireland. The current study presents results from the first four years of a study which will continue for a much longer time period to assess long-term varietal performance.

Materials and methods

This was a longitudinal study of grass performance on 475 paddocks across 79 grassland farms during the period January 2013 - December 2016. Farms which varied in agroclimatic regions, on differing soil types and operating grass-based spring calving herds were identified and enrolled. PastureBase Ireland (Hanrahan *et al.*, 2017) is a web-based grassland database which has a dual function of providing real time decision support for farmers while acting as a national grassland database. All grassland information is recorded by the farmer through a web interface. Within PastureBase Ireland (PBI) the drainage characteristics of each paddock were also categorised. A range in pH across all farms was noted with a pH average of 6.30 operating at between 170 and 250 kg N ha^{-1} yr^{-1} across paddocks with an additional allowance of 250 kg of inorganic N ha^{-1} yr^{-1}.

Grass varieties were sown in monocultures in individual paddocks from 2011 to 2015 on all of the 79 commercial farms according to stringent guidelines to ensure that swards were established successfully. Varieties with a range in heading dates were selected and all farms were allocated tetraploid and diploid varieties. Grass DM production was measured from 01 January to 31 December annually. Grazing and silage DM yields were assessed prior to grazing or harvest and were recorded in PBI. The effect of variety on DM production was estimated using a mixed linear model in PROC MIXED (SAS inst. Inc., Cary, NC, USA) with paddock nested within farm included as a repeated measure with a compound symmetry covariance structure assumed among paddocks within a farm.

Results and discussion

There was a variety by year interaction ($P < 0.001$) for total and grazing DM yield. There was a significant ($P < 0.001$) effect of variety on total and grazing DM yield. The highest performing variety for total DM yield was AberMagic (13,653 kg ± 435) and the lowest yielding variety was Glenveagh (11,993 kg ± 367). The highest yielding variety with respect to grazing DM was Astonenergy (12,024 kg ± 357) and the lowest yielding variety was Dunluce (10,101 kg ± 431). No variety effect existed for the number of cuts or yield of silage, although differences existed between individual varieties (Table 1). This study presents the first four years of a long-term study assessing the performance of varieties on commercial farms. Grazing DM performance indicate how well a variety performs from a grazing perspective, with more frequently grazed swards having greater DM production. The on-farm evaluated varieties were found to produce significantly different yields of grazed herbage. Astonenergy achieved the highest yield of grazed herbage, but combined with a low silage yield. Astonenergy appears to be ideally suited to an intensive grazing regime. This allows for lower post-grazing residuals to be achieved, thereby increasing the number of grazing events without the need to remove surplus grass. Varieties such as AberGain, Astonenergy, Dunluce, Glenveagh, Kintyre, Twymax and Tyrella appeared to have good yield stability as their DM production increased annually; the remaining varieties (each of which were diploid varieties) all experienced reduced DM production in either 2014, 2015 or 2016. Longer time frames which allow swards to mature are required to assess DM yield stability as outlined by Parsons *et al.* (2011). Examining the cumulative yield of varieties over 5- or 10- year periods would provide a better indication.

Table 1. DM yield (kg ha^{-1}) of varieties of perennial ryegrass for total, grazing and silage production.

Total DM production			DM produced for grazing			DM produced for silage		
Variety (ranked from high to low yield)	kg DM ha^{-1}	SE	Variety (ranked from high to low yield)	kg DM ha^{-1}	SE	Variety (ranked from high to low yield)	kg DM ha^{-1}	SE
AberMagic	13,653	435.4	Astonenergy (T)	12,024	357.6	Dunluce (T)	2,033.0	355.2
AberGain(T)[1]	13,433	274.8	AberChoice	11,898	405.0	AberMagic	1,957.8	493.9
Astonenergy (T)	13,254	261.0	Drumbo	11,880	396.2	AberGain (T)	1,847.5	299.1
AberChoice	13,092	297.7	AberMagic	11,670	599.4	Twymax (T)	1,691.7	287.5
Drumbo	13,062	289.9	AberGain(T)	11,590	363.5	Majestic	1,662.1	435.9
Kintyre (T)	12,919	261.8	Kintyre (T)	11,448	356.7	Glenveagh	1,564.5	406.6
Tyrella	12,918	179.4	Tyrella	11,396	241.7	Tyrella	1,504.4	199.0
Twymax (T)	12,900	260.5	Twymax (T)	11,163	349.2	Kintyre (T)	1,449.0	293.9
Dunluce (T)	12,219	319.0	Majestic	10,466	529.5	Astonenergy (T)	1,192.9	294.7
Majestic	12,157	395.7	Glenveagh	10,442	493.9	Drumbo	1,192.1	326.5
Glenveagh	11,993	367.3	Dunluce (T)	10,101	431.4	AberChoice	1,156.79	333.6

[1] (T) indicates a tetraploid variety; all other varieties are diploid.

Conclusion

Overall, variety was found to have a significant effect on total herbage production on-farm, grazing yield also differed by variety. Not only does the current study demonstrate the importance of on-farm variety evaluation, but also, it examines the value of a variety under an intensive grazing regime. This study has increased the level of understanding on individual varieties true agronomic potential. Current and future developments in grass evaluations in Ireland need to identify improved varieties suited to intensive grazing environments.

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Portable NIRS: a novel technology for the prediction of forage nutritive quality

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Abstract

The present research aimed to test the efficacy of portable near-infrared spectroscopy (NIRS) instrumentation in estimating nutritive quality parameters of perennial ryegrass (*Lolium perenne* L.). The DM, crude protein (CP), acid detergent fibre (ADF) and water-soluble carbohydrate (WSC) content of 96 fresh perennial ryegrass samples from sites around Northern Ireland were predicted using three portable NIRS instruments, denoted as PN-A, PN-B and PN-C. In addition, the samples were analysed using a laboratory NIRSystems 6500 (Lab-6500) which acted as a qualitative reference instrument. Paired t-tests were employed to determine the accuracy of each instrument in reciprocating the predictions of the Lab-6500. PN-A accurately predicted CP and WSC content ($P = 0.605$ and $P = 0.692$, respectively) but was unable to produce DM or ADF predictions that were comparable with the Lab-6500. PN-B did not replicate Lab-6500 predictions for DM, CP, ADF or WSC and PN-C predicted DM content similar to Lab-6500 data ($P = 0.269$), but did not produce similar predictions of CP and ADF (not calibrated for WSC). Overall, no portable NIRS instrument was capable of replicating the Lab-6500 predictions for all the quality parameters and the potential to create correction factors was discussed.

Keywords: NIRS, forage quality, *Lolium perenne*

Introduction

Near-infrared spectroscopy (NIRS) is the dominant advisory tool used for the accurate prediction of forage nutritive quality (Norris *et al.*, 1976). This analytical technique measures the absorption of radiation in the near-infrared range of the electromagnetic spectrum (780 - 2500 nm), which can be used to estimate the chemical composition of organic substances (Shenk *et al.*, 1979). Using a set of preloaded calibration equations, fundamental nutritive parameters of forages including DM, water soluble carbohydrate (WSC), crude protein (CP) and acid detergent fibre (ADF) content can be simultaneously calculated from these absorption measurements (Shenk *et al.*, 1979). Recently, portable NIRS instruments have emerged as a novel technology with the potential to enhance farming practice by providing on-farm, real-time nutritive quality predictions (Berzaghi *et al.,* 2005; Dos Santos *et al.*, 2013). To date, there are few independent studies that have quantified performance against a known laboratory reference NIRS. Therefore, the objective was to test the efficacy of three portable NIRS instruments to predict the nutritive quality of fresh perennial ryegrass (*Lolium perenne* L.) in comparison with a quality controlled laboratory NIRS system.

Materials and methods

A total of 96 perennial ryegrass samples were analysed for a range of nutritive characteristics. Samples were collected between April and August 2017 from both commercial farms and research projects conducted by AFBI Hillsborough. All samples were taken from perennial ryegrass dominant swards of a range of ages, managed under rotational grazing and frequent cutting regimes. Samples were analysed by a laboratory NIRS instrument, NIRSystems 6500 (Foss, Hillerød, Denmark), denoted as Lab-6500. Three portable NIRS instruments from different manufacturers were used for the comparisons and denoted as PN-A, PN-B and PN-C. The Lab-6500 was operated at the AFBI Hillsborough ISO17025 certified laboratory, making use of robust calibrations developed specifically for the analysis of fresh grass in Northern Ireland. Therefore, this instrument acted as a reliable laboratory prediction standard against which predictions produced by the portable instruments could be compared.

Prior to analysis, each sample was chopped into approximately 25 cm lengths and mixed well. For Lab-6500, three random 100 g subsamples were taken from each sample and scanned at 2 nm intervals over the wavelength range 1100 - 2498 nm. Following NIRS analysis, the subsamples were recombined and mixed well for subsequent portable NIRS analysis. Three random 100 g subsamples were again taken from each sample and scanned using each portable NIRS instrument consecutively, with the scanning method varying according to each instrument's requirements. For each sample, mean DM, CP, ADF and WSC content was determined from the subsamples (except for PN-C which was not calibrated to predict WSC content). Data analysis was conducted by Minitab statistical software. Data was tested for normality and paired t-tests employed to determine if significant differences occurred between predictions returned by each portable NIRS instrument and the Lab-6500. A significant difference was defined as $P < 0.05$.

Results and discussion

The PN-A (Table 1) predicted CP and WSC to a level comparable with the Lab-6500 ($P = 0.605$ and $P = 0.692$, respectively). The PN-A was, however, unable to accurately predict DM ($P < 0.05$) or ADF ($P < 0.05$). Although PN-A returned a similar CP mean to the Lab-6500 it did so with a reduced overall range of values compared to the Lab-6500. This indicated an ability to accurately predict intermediate CP contents but an inability to accurately detect samples at the high or low end of the range. The PN-A provided a good prediction of WSC content, producing a similar prediction range to the Lab-6500, but exhibited a consistent under-prediction bias for ADF that resulted in a lower prediction range and, therefore, a significantly lower mean. For DM, PN-A returned a much higher minimum value than the Lab-6500, indicating a weakness in predicting DM in wetter grasses. This contributed to a consistent DM over-prediction trend across the range of samples, ultimately producing a significantly different mean.

The PN-B (Table 2), did not replicate the Lab-6500 predicted values for DM ($P < 0.05$), CP ($P < 0.05$), ADF ($P < 0.05$) or WSC ($P < 0.05$). Despite PN-B sharing a similar maximum value, minimum value and range with the Lab-6500 there was still a tendency for some over-prediction of DM at low DM contents, and under prediction at high DM contents. The PN-B also failed to reliably match the Lab-6500 for CP, with a greatly reduced range of predicted values and a minimum value 11.7% higher than the Lab-6500. This contributed to a profound and consistent over-prediction bias. For both ADF and WSC predictions, PN-B displayed a consistent and profound under-prediction bias at an average of 4.1 and 10.9% respectively.

The PN-C (Table 3), predicted a DM mean that was statistically similar ($P = 0.269$) to the Lab-6500 but produced significantly different CP ($P < 0.05$) and ADF ($P < 0.05$) means. Predictions returned for

Table 1. Statistical comparison of portable PN-A with control laboratory NIRS (LAB - 6500).

Parameter	Instrument	N	Mean	St. dev	Minimum	Maximum	Range	T-value	*P*-value
DM	Lab-6500	60	19.12	1.75	16.01	24.10	8.09	-19.93	< 0.05
	PN-A	60	21.96	1.24	19.83	25.30	5.47		
CP	Lab-6500	60	16.17	3.74	8.58	23.91	15.33	0.52	0.6048
	PN-A	60	15.96	1.34	13.43	18.77	5.34		
ADF	Lab-6500	72	28.25	2.16	22.39	32.88	10.49	20.90	< 0.05
	PN-A	72	23.48	1.50	19.97	26.90	6.93		
WSC	Lab-6500	60	18.75	3.64	12.56	26.68	14.12	-0.40	0.6923
	PN-A	60	18.87	2.54	13.23	24.10	10.87		

Table 2. Statistical comparison of portable PN-B with control laboratory NIRS (LAB-6500).

Parameter	Instrument	N	Mean	St. dev	Minimum	Maximum	Range	T-value	*P*-value
DM	Lab-6500	34	19.15	1.87	16.01	22.40	6.39	-2.97	< 0.05
	PN-B	34	19.64	1.17	17.34	22.22	4.88		
CP	Lab-6500	34	14.62	4.70	8.25	22.70	14.45	-12.52	< 0.05
	PN-B	34	22.37	1.55	19.95	25.97	6.02		
ADF	Lab-6500	34	27.25	2.12	22.39	32.33	9.94	14.38	< 0.05
	PN-B	34	23.11	1.11	20.84	24.89	4.05		
WSC	Lab-6500	34	20.58	4.02	13.07	26.52	13.45	15.40	< 0.05
	PN-B	34	9.71	0.75	8.58	11.43	2.85		

Table 3. Statistical comparison of portable PN-C with control laboratory NIRS (LAB-6500).

Parameter	Instrument	N	Mean	St. dev	Minimum	Maximum	Range	T-value	*P*-value
DM	Lab-6500	72	18.15	3.15	9.68	24.10	14.42	-1.12	0.2685
	PN-C	72	18.35	2.09	12.87	21.80	8.93		
CP	Lab-6500	72	15.62	4.67	8.25	25.12	16.87	-7.64	< 0.05
	PN-C	72	18.78	3.29	14.27	29.37	15.10		
ADF	Lab-6500	72	29.31	3.07	22.39	34.85	12.46	17.96	< 0.05
	PN-C	72	23.61	2.28	17.80	29.97	12.17		

DM were accurate with no significant over-prediction or under-prediction apparent. For CP, PN-C had a higher minimum value than the Lab-6500 which resulted in an over-prediction bias at low CP values. The PN-C exhibited a consistent under-prediction bias for ADF which was more profound at higher CP values.

Conclusion

As WSC is an important component of herbage evaluation for ruminant nutritional value, the absence of a calibration is a large drawback of the PN-C instrument. Overall, no instrument accurately replicated bench NIRS predictions for all four quality parameters. However, potential exists to employ a correction factor where biases are consistent but over and under-prediction biases were frequent. While this was likely due to their calibration equations being built for a sample set different to that examined, the sample set used in this study was typical of the material produced from grassland farms in Ireland. Creating an effective correction factor in these cases will be quite difficult, but the use of larger, more variable calibration sample sets may provide better prediction accuracy, though this would again need to be validated against a reference laboratory NIRS for a typical range of test samples.

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Impact of harvesting technique and storage duration on perennial ryegrass nutritive quality deterioration

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Abstract

Zero-grazing is a novel harvesting technique purported to minimise mechanical damage to grass during harvest and thus, reduce post-harvest (P-H) spoilage. The objective of the present research was to test the ability of a zero-grazing harvesting treatment to reduce P-H quality deterioration in perennial ryegrass (*Lolium perenne L.*), when compared to a traditional harvesting technique (double chopping). A total of 240 ryegrass samples harvested using zero-grazing or double chopping were stored for varying periods (0, 6, 24, 30 or 48 h). Near-infrared spectroscopy (NIRS) was then utilised to provide predictions of DM, water-soluble carbohydrate (WSC), crude protein (CP) and acid detergent fibre (ADF) content as indicators of nutritive quality. Analysis showed that double chopped grass exhibited greater DM and WSC declines than zero-grazed grass (0.48 and 1.12% greater, respectively) and a 0.15% greater accumulation of ADF over a 48 h period. In contrast, zero-grazed grass exhibited a 0.46% greater CP decline than double chopped grass. The results indicate that overall, zero-grazing preserves the nutritive quality of harvested grass better than double chopping.

Keywords: NIRS, forage quality, zero-grazing, *Lolium perenne*

Introduction

Zero-grazing (ZG), a system whereby dairy cows are housed throughout the year and cut grass is presented to the cow, is gaining popularity in the UK and Ireland following a trend of increased intensification in livestock production (Kristensen *et al.*, 2005; Haskell *et al.*, 2006). Whilst ZG results in restricted grazing at pasture, fresh grass forages remain a significant dietary constituent in ZG systems. The nutritive content of fresh grass, however, becomes unstable post-harvest (P-H) due to mechanical damage caused by the harvesting procedure (Rotz and Muck, 1994). This quality deterioration can impair the value of fixed feeding regimes designed to fulfil the dietary demands of cattle. Despite the significant implications, little is known about the rate of P-H quality deterioration and the impact different harvesting strategies have. Companies operating in the UK and Ireland have developed specialised ZG harvesting equipment with the apparent ability to minimise damage to grass during harvesting and, therefore, decrease the extent of P-H spoilage. Near-infrared spectroscopy (NIRS) is the foremost technique used for forage nutritive quality evaluation due to its speed, accuracy and multi-constituent analysis ability (Burns *et al.*, 2010). Therefore, this study employed AFBI's NIRS calibrations to determine the impact of ZG equipment on the rate and degree of P-H quality deterioration in perennial ryegrass (*Lolium perenne L.*).

Materials and methods

Perennial ryegrass samples were harvested from ten experimental plots at AFBI Hillsborough, from June to August 2017. Two harvesting methods were used to collect grass from the experimental plots; ZG using a specialised ZG harvester and double chopping (DC) using a traditional double chop harvester. Herbage collected via each method was divided into 600 g (± 1) samples, each of which was placed into an expanded polystyrene 'fish box' for storage. To determine how the nutritive quality of the harvested herbage changed with time, 5 P-H analysis time points were selected; 0 h, 6 h, 24 h, 30 h and 48 h. Twenty-four boxes of herbage were used as replicates for each storage length treatment, giving a total of

120 samples for each of the two harvesting treatments. Each box was allocated to a P-H analysis time point and stored at room temperature in the dark until that time point was reached.

At every sample time, three 100 g (+1) subsamples were randomly selected from each replicate box and an NIRSystems 6500 (Foss, Hillerød, Denmark) employed to provide a mean nutritive quality profile per sample. Subsamples were chopped to approximately 25 mm length blades, inserted into the NIRSystems 6500 and scanned at 2 nm intervals over the wavelength range 1,100-2,498 nm. The DM, water-soluble carbohydrate (WSC), crude protein (CP) and acid detergent fibre (ADF) content of each subsample were predicted. Data analysis was completed on Minitab statistical software. Paired t-tests and one-way analysis of variance (ANOVA) tests in conjunction with Tukey's tests were conducted to compare the effects of ZG and DC harvesting treatments on forage nutritive quality change. Significance was reported at $P < 0.05$.

Results and discussion

Dry matter losses of 1.13 and 1.61% were observed between 0 and 48 h for ZG and DC grasses, respectively (Table 1), but these were not statistically significant changes ($P= 0.439$ and $P= 0.278$, respectively). However, a DM loss of this magnitude would have a measurable impact on the milk yields of dairy cattle, equating to a loss of approximately 2.20 litres per day. Therefore, further analysis was conducted, involving a paired t-test to compare ZG and DC means at 0 h. This also showed no significant difference in DM content ($P = 0.721$). However, a t-test comparing DM means at 48 h showed DC to be significantly lower than ZG ($P= < 0.05$). This indicated that DM loss in DC forage is significantly greater than in ZG forage and confirms that ZG can significantly reduce P-H spoilage.

Both ZG and DC treatments experienced mean WSC loss of 2.50 and 3.62%, respectively, between 0 and 48 h (Table 1). The greater loss in DC forage was shown by an ANOVA to be a significant decline ($P = 0.008$), whereas, the ZG decline was statistically insignificant ($P = 0.073$). This finding was not unexpected as the greater mechanical damage inflicted on DC forage during harvest allows for a more rapid onset of P-H respiration, which uses WSC as a primary substrate. Again, this indicates that ZG can significantly reduce PH spoilage.

For CP, ANOVA tests showed no significant change in content for either ZG or DC treatments ($P= 0.853$ and $P= 0.999$, respectively) between 0 and 48 h. Paired t-tests comparing ZG and DC means at 0 h and 48 h both showed CP content to be significantly lower in ZG than in DC grass ($P = 0.002$ and $P = 0.001$, respectively). The more extreme P value at 48 h suggests that ZG grass experienced a more rapid loss of CP content over the 48 h period. This is reflected by a greater mean percentage loss of 0.64% in ZG compared to 0.18% loss in DC (Table 1). Crude protein deterioration occurs P-H via proteolysis; degrading proteins to non-protein nitrogen compounds. It would be expected that proteolysis would proceed at a greater rate in DC grasses due to the greater extent of mechanical damage inflicted, however, the results do not reflect this. It is possible that the greater loss of other substances comprising DM content in DC forage, such as WSC, masks the loss of CP content as a percentage of DM.

Both ZG and DC forage exhibited an increase in ADF content (1.45 and 1.60%, respectively) between 0 and 48 h (Table 1). The ANOVA tests showed both to be significant increases ($P = 0.024$ and $P = 0.013$). This was expected as ADF content should be unaffected by P-H deterioration and, therefore, will increase as a percentage of DM content as other components deteriorate. The lesser accumulation of ADF in ZG forage indicates a lesser degree of overall quality deterioration and supports the theory that ZG significantly reduces P-H spoilage.

Table 1. Change in ryegrass quality parameters over a 48 h period post-harvest (in all analyses sample number was 24).

Quality parameter	Statistic	Treatment and time point (h)									
		Zero-grazed					Double chopped				
		0	6	24	30	48	0	6	24	30	48
Dry matter	Mean	16.97	16.44	16.60	16.08	15.84	16.87	16.86	16.60	15.76	15.26
	StDev	2.54	2.34	2.34	2.14	2.18	3.17	2.84	2.34	2.55	2.83
	Minimum	11.23	10.95	10.72	10.13	10.84	9.68	10.49	10.72	10.03	9.07
	Maximum	21.27	18.40	19.53	19.17	18.63	19.3	19.07	19.53	18.06	18.96
	Range	10.04	7.45	8.81	9.04	7.79	9.62	8.58	8.81	8.03	9.89
Water soluble	Mean	16.41	15.89	15.72	14.10	13.91	13.57	13.40	12.04	10.86	9.95
carbohy-drates	StDev	3.51	3.25	3.42	3.17	3.16	4.03	3.15	3.84	3.81	3.53
	Minimum	7.08	7.75	7.36	4.86	6.64	3.13	6.68	1.25	2.83	1.72
	Maximum	20.81	19.63	20.42	18.31	18.23	17.30	17.22	16.59	15.45	13.70
	Range	13.73	11.88	13.06	13.45	11.59	14.17	10.54	15.34	12.62	11.98
Crude protein	Mean	17.32	16.91	16.56	16.94	16.68	18.58	18.16	18.77	18.83	18.40
	StDev	2.32	2.20	2.37	1.95	2.11	2.61	2.23	2.84	2.56	2.78
	Minimum	12.18	11.97	10.55	11.98	12.18	14.65	14.82	14.46	15.30	14.67
	Maximum	23.26	20.23	19.66	19.38	19.45	25.12	22.96	25.97	23.99	23.83
	Range	11.08	8.26	9.11	7.40	7.27	10.47	8.14	11.51	8.69	9.16
Acid detergent fibre	Mean	31.08	31.56	31.60	32.39	32.53	31.17	31.25	31.67	32.39	32.77
	StDev	1.94	1.62	1.55	1.64	1.41	2.11	1.73	1.82	1.46	1.29
	Minimum	27.22	28.88	28.36	28.95	28.93	26.97	27.67	28.98	29.28	29.82
	Maximum	33.41	34.68	34.69	34.98	35.14	34.85	34.22	34.70	34.4	34.57
	Range	6.19	5.80	6.33	6.03	6.21	7.88	6.55	5.72	5.12	4.75

Conclusion

This investigation displayed the greater ability of ZG harvesting equipment to preserve the nutritive quality of perennial ryegrass compared to a more traditional harvesting method. This ability of ZG to reduce P-H spoilage can ensure that a greater proportion of the nutritional value of freshly harvested forage gets into cattle diets and so contributes to reducing the contribution of expensive concentrated feeds to maintaining animal performance.

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‘Smart grazing’: modelling grass growth in rotationally grazed pastures

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Abstract

In order to close the knowledge gap on yield and forage quality dynamics of rotationally grazed pastures in northern Germany, we measured grass growth in a simulated grazing approach under two fertilisation regimes (0 and 280 kg N ha^{-1} y^{-1}). Measurements were conducted at three sites representing different soil types during two experimental years. Results showed high DM yields of up to 18.5 t DM ha^{-1} y^{-1}. We will use these data to calibrate a pasture model to predict daily DM yield increment and forage quality dynamics by extending existing model tools, currently used for prediction of the best cutting dates for grass (FoProQ) and maize (MaisProg) silage. For optimal results, the new model tool ‘Smart grazing’ requires weather and specific sward input data when a simulation run starts, to derive feasible values for relative growth rate and initial biomass. First model calibrations for DM yield are presented in this paper.

Keywords: grazing management, modelling, crop growth rate, relative crop growth rate

Introduction

Inter- and intra-annual variability in grass growth in temperate regions poses challenges for farmers regarding management of dairy cow feeding from pastures. Decision support tools such as models forecasting daily pasture growth rate (DPGR) are essential to meet these challenges in an optimised pasture management system. In northern Germany, tools with high validity exist for grass (FoProQ) and maize (MaisProg) silage production that aim to forecast the best date for harvesting high quality forage (Kornher *et al.*, 1991; Herrmann *et al.*, 2005a,b). But none exist that aim to forecast DPGR as a basis for an optimised management of rotational grazing systems, in order to achieve high forage use efficiencies and good quality grazed swards. The reason for this omission may be observed in the trend towards high intensive confinement milk production systems, based on maize and grass silage feeding during recent decades, which led to a data-gap on pasture growth and quality. However, due to low production costs and consumer preferences, grazing systems are experiencing a renaissance. The main objectives of the presented ‘Smart grazing’ project are therefore, to (1) fill the existing data and knowledge gap, (2) modify the FoProQ-model for pasture growth and (3) calibrate and validate the model with the collected data.

Materials and methods

In the FoProQ-model, an index for crop ageing based on leaf area indices is limiting growth rates, and a growth index that consists of indices for temperature, radiation, available soil water and nitrogen, each ranging from 0 to 1, represents the influence of weather conditions on DPGR. For model calibration, data are needed that represent typical growth curves for defined sward types. These data should include sward composition and tiller morphology (e.g. vegetative or reproductive) in order to derive coefficients for initial biomass and starting values for relative growth rate (RGR), thus allowing numeric simulation runs. Therefore, field experiments on grazed paddocks of commercial farms were initiated on three contrasting soil types representing the main landscapes in the state of Schleswig-Holstein in northern Germany (Figure 1). The soil types ranged from sand to loam and silty loam with a high percentage of clay (Table 1). Based on existing records of botanical composition, perennial ryegrass dominated swards (threshold share of at least 50% of perennial ryegrass) were selected. At the beginning of each growing season, exclosures (experimental set-up with exclusion of animals) were implemented in the grazed paddocks and plots designed to derive the growth curves based on Corral and Fenlon (1978). In each year, the exclosures were shifted within the grazed paddocks to an area grazed in the previous year, to represent the grazing situation regarding sward composition and DPGR. Grass samples were cut by hand on an area of 0.25 m^2 at a height of 4 cm above ground in each plot. The sampling procedure was conducted in two experimental years (2016 - 2017) at two mineral nitrogen fertilisation levels: 0 (to calculate nitrogen release from the soil) and 280 kg N ha^{-1} y^{-1} (35 kg N ha^{-1} each four weeks), representing an expected optimum level for grass growth. Meteorological data was available from weather stations of the German National Meteorological Service, located close to the experimental sites.

Results and discussion

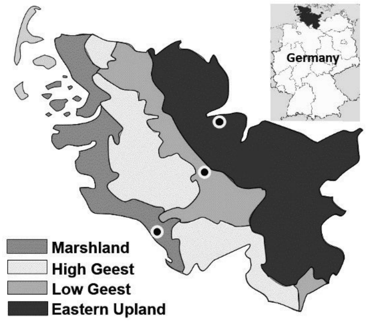

Figure 1. Location of the experimental sites in Schleswig-Holstein.

Table 1. Soil type, grain size composition, usable field capacity of the examined sites.

Landscape	Marshland	Geest	Eastern Upland
Soil type	silty loam	sandy sand	loamy sand
Grain composition % (Clay/Silt/Sand)	(30/50/20)	(5/9/86)	(14/27/59)
Usable field capacity (0-30 cm)	84 mm	42 mm	80 mm
Prec. sum (2016)	875 mm	766 mm	650 mm
Prec. sum (2017)	1007 mm	1044 mm	888 mm
Temp. mean (2016)	9.9 °C	9.6 °C	9.6 °C
Temp. mean (2017)Ø 1981-2010)	9.8 °C	9.5 °C	9.8 °C

Differences in DPGR of the sites in the 280 kg N ha^{-1} treatment for 2016 and 2017 are shown in Figure 2. Due to higher precipitation during the season and a warmer spring, conditions for grass growth were beneficial in 2017 and resulted in high DPGR. In 2016, DPGR were lower due to a colder spring and lower precipitation rates in the summer and autumn.

Average annual yields were highly influenced by N-fertilisation level ranging between 17.6, 16.9 and 18.5 t DM ha^{-1} y^{-1} under full nitrogen fertilisation for the soil types silty loam, sandy sand and loamy sand, respectively, while yields of the swards without N-fertilisation were on average 30% lower. Using the presented DPGR data for first calibrations, first runs result in a promising correlation between simulated and observed data (Figure 3 and 4). Next steps will include model tests with data sets for validation and extended versions for forage quality parameters.

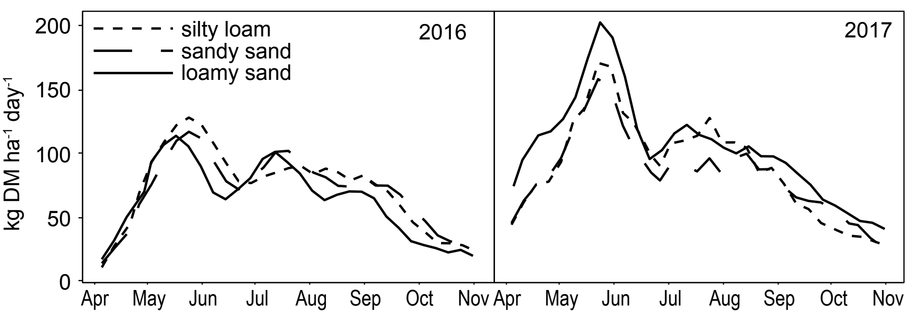

Figure 2. Daily pasture growth rates (kg DM ha^{-1} day^{-1}) of the examined sites in 2016 and 2017 with N-fertilisation of 280 kg N ha^{-1} y^{-1}.

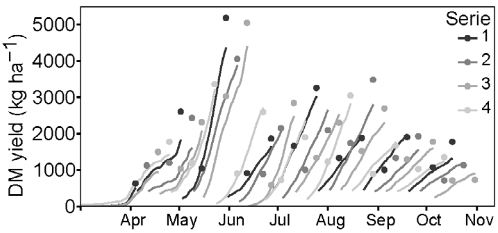

Figure 3. An example of simulated growth curves (lines) and measured values (points).

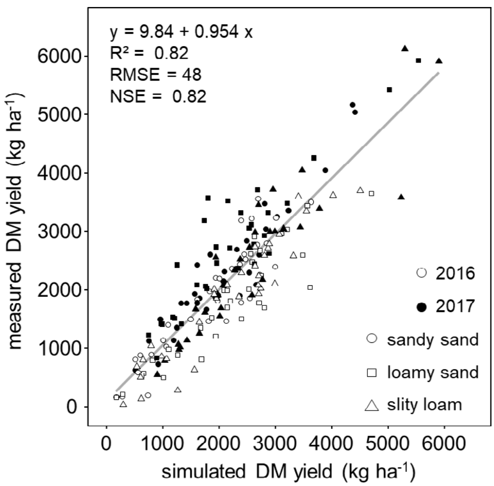

Figure 4. Statistical evaluation of the FoProQ model quality between simulated and observed values. Model performance was evaluated by coefficient of determination (R^2), root mean squared error (RMSE) and Nash-Sutcliffe model efficiency coefficient (NSE) (Pushpalatha *et al.*, 2012).

Conclusion

Comparing the growth curves with those from highly productive sites in southern Ireland (see Loges *et al.* in this issue) underlines the good environmental conditions for grass growth in northern Germany and thus, the high potential of re-implementing intensive grazing systems, provided that on-farm infrastructure is available. FoProQ calibrations indicate the suitability of this model as a powerful tool for grass growth simulation and can thus be implemented in extension services for the support of pasture management in northern Germany.

Acknowledgements

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Methods for spatially explicit estimation of NATURA 2000 grassland forage quality using satellites

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Abstract

Spatially explicit mapping of grassland forage quality is of major interest for sustainable grazing management of NATURA 2000 areas, especially if those are large or have limited accessibility. Therefore, this study is concerned with the estimation of crude protein (CP) and organic acid detergent fiber (oADF) content at regional scale using Sentinel-2 and Landsat 8 remote sensing data. Field data were collected in the Grafenwoehr military training area in Bavaria, Germany. Different combinations of predictor variables were applied using cross-validated random forest regression, linear regression with lasso penalty and linear regression with ridge penalty models. The red-edge band of Sentinel-2, centered at 705 nm, as well as the shortwave infrared bands of both sensors and related vegetation indices contributed the most to the respective models. Linear regression with lasso penalty and Sentinel-2 data performed consistently better, compared to the other models. The results (CP (10.1 - 23.1%): max R^2 0.53, RMSE 1.78%; oADF (22.7 - 39.5%): max R^2 0.72, RMSE 2.3%) demonstrate the potential of remote sensing as an information tool in supporting the conservation management of grassland areas with limited access.

Keywords: remote sensing, regression, forage quality, wildlife grazing, NATURA 2000

Introduction

Regional mapping of grassland forage quality is of major interest for sustainable grazing management of NATURA 2000 areas, especially if they are large or have limited accessibility. The availability and quality of potential forage areas affects the spatial distribution and activities of herbivores (Merkle *et al.,* 2016) and thus their influence on the ecosystem by e.g. grazing, trampling and nutrient cycling (Fløjgaard *et al.,* 2017). Spatially continuous information about the quality of grassland can be seen as pivotal to understanding the spatial and temporal behaviour, as well as the sustainable management and conservation of wildlife, such as red deer (*Cervus elaphus*). Therefore, this study is concerned with the prediction of crude protein (CP) and organic acid detergent fiber (exclusive of residual ash, oADF) by remote sensing and field data using different combinations of predictor variables and regression models. We hypothesise that (1) a relationship between CP, oADF and spectral information obtained by remote sensing exists; (2) a relevant subset of predictor variables can be identified to be sufficient for predicting grassland forage quality; and (3) a higher spectral resolution is superior to a higher spatial resolution.

Materials and methods

The study was conducted on the military training area Grafenwoehr (GTA) in Bavaria, Germany (49° 40' 56'' N, 11° 47' 20'' E; about 230 km^2). Roughly 85% of the GTA are part of the NATURA 2000 network and contain numerous rare and highly protected habitat types (Warren and Büttner, 2008). To map the grass CP and oADF content at regional scale (about 200 ha) 72 grass samples were collected (16 - 18 May 2017). At each sampling location, grass was clipped within a 10 m radius (simulated grazing by hand plucking) and dried at 60 °C for 48 h. Subsequently, we measured all samples for CP and oADF content using near infrared spectroscopy (NIRS). Access to the study sites was restricted due to military use and to avoid wildlife disturbance. Landsat 8 (path = 193, row = 25) and Sentinel-2 (T32UPA) surface reflectance data, acquired on 17 May 2017, were obtained from the EarthExplorer and Sentinel Data Hub, respectively. In addition to the multi-spectral bands (MS), a list of commonly used vegetation indices (VI) (Sentinel-2 20 m: n = 89; Landsat8 30 m: n = 40) and texture (TXT) measures (n = 28 for each) were included. We included Sentinel-2 data resampled to 30 m as a third data set. Different combinations of standardised predictor variables (MS+VIs, MS+TXT and MS+VIs+TXT) were applied using linear regression with lasso penalty (LRL), linear regression with ridge penalty (LRR) (lambda optimised using cross-validation) and random forest regression (RF) (ntree = 1000, mtry = p/3) models. All models were cross-validated (k = 5) with 100 repetitions and variable importance was calculated as mean decrease of RMSE (100 permutations) using the *sperrorest* package implemented in R (v3.4.1; R Core Team 2017).

Results and discussion

The range of NIRS results for CP and oADF was: 10.1 - 23.1% (average 15.9% and *sd* (standard deviation) 2.6%), 22.7 - 39.5% (average 29.7% and *sd* 4.5%), respectively. On average, the LRL (mean R^2: CP = 0.42, *sd* = 0.08; oADF = 0.64, *sd* = 0.064) models were superior to LRR (mean R^2: CP = 0.34, *sd* = 0.13; oADF = 0.57, *sd* = 0.12) and RF (mean R^2: CP = 0.26, *sd* = 0.08; oADF = 0.51, *sd* = 0.15). The moderately high R^2 values support hypothesis (1). As illustrated in Figure 1, the best model performance for CP was obtained using the Sentinel-2 20 m data, combining MS and VI predictor variables (RMSE: 1.78, *sd* = 0.06). For oADF, the Sentinel-2 30 m data with the same variable combination performed best (RMSE: 2.3, *sd* = 0.06). In addition, the SR green divided by red-edge (Sentinel-2 band 5, at 705 nm), the NMDI (Normalized Multi-band Drought Index) and the PSRI (Plant Senescence Reflectance Index) can be seen as important contributors to the model performance (Figure 2). Confirming hypothesis (2), the derived variable importance levels in Figure 2 indicate the strong relevance of the SWIR (shortwave infrared) bands for the prediction of CP and oADF. The presented results indicate the strength of LRL in selecting the most important variables by penalising, and consequently disregarding, the less relevant predictors. As reported by Verrelst *et al.* (2015), only few studies concerned with the prediction of bio-physical parameters using LRL exist, even though LRL seems to perform better than other regression methods in a high-dimensional data context (Zandler *et al.,* 2015). The Sentinel-2 sensor with a higher spectral resolution showed better performance results compared to Landsat 8, confirming hypothesis (3). This was supported by the derived variable importance levels (Figure 2), which underlined the importance of the red-edge bands for mapping CP and oADF. The SWIR-associated variables can be seen as essential,

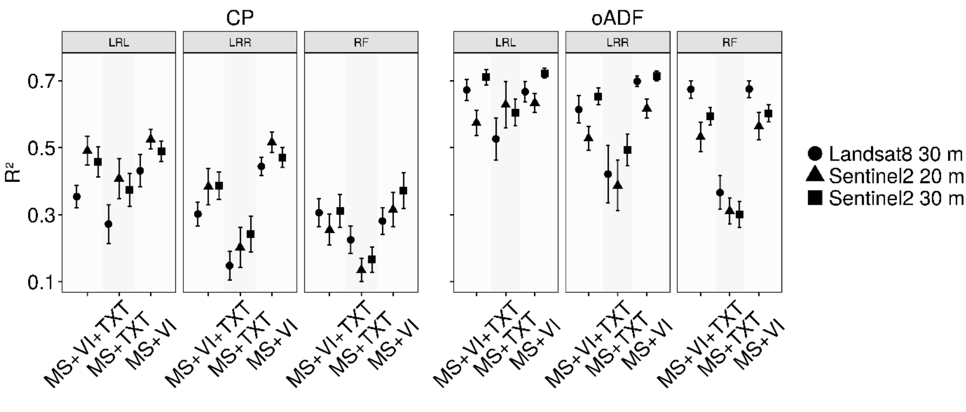

Figure 1. Cross-validated (100 repetitions) R^2 values for the estimation of CP and oADF using different predictor combinations (MS = multi-spectral, VI = Vegetation indices, TXT = texture) and regression models (LRL = linear regression with lasso penalty, LRR = linear regression with ridge penalty, RF = random forest regression).

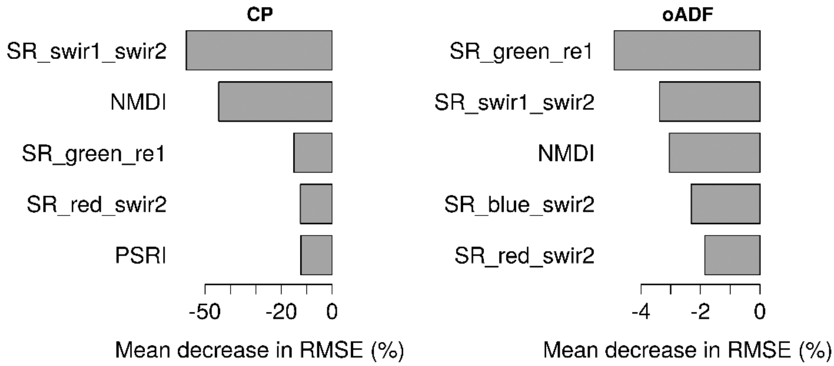

Figure 2. Permutation-based variable importance for CP (Sentinel-2 20m, MS+VI) and oADF (Sentinel-2 30m, MS+VI). SR = simple ratio, NMDI = Normalized Multi-band Drought Index, PSRI = Plant Senescence Reflectance Index, re1 = Sentinel-2 band 5, at 705 nm.

as they can be related to the moisture content of soil and vegetation, which is associated with vegetation health and, accordingly, CP and oADF content.

Conclusion

Remote-sensing-based regression models have potential for mapping grassland forage quality, and can, therefore, support the conservation management and monitoring of grassland areas with limited access. The high spectral resolution of Sentinel-2, especially the red-edge and SWIR bands can be seen as crucial for good performance. Future research should investigate the potential of pan-sharpened Sentinel-2 data and LRL-based forage quality estimation.

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Multispectral imagery from UAVs to classify and monitor vegetation change in semi-natural grasslands

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Abstract

The use of multispectral imagery achieved from fixed-wing unmanned aerial vehicles (UAVs) has the capability to deliver high resolution imagery that can be used to monitor vegetative composition and change in semi-natural grasslands. Using a multispectral camera mounted on a fixed wing UAV with autonomous flight capability, this study is classifying and monitoring vegetation at three sites, each > 70 ha, in mid-Wales, across a three-year period. Acquired imagery is stitched and georeferenced orthomosaics produced. Vegetation classification is achieved through a supervised pixel-based classification using the random forest classifier, accessed from the open-source python interface software package RSGISLib. The relatively low cost of this method has the potential to deliver a wide range of environmental and agricultural services on differing types of grasslands and wider vegetative communities; whether it be increasing the accuracy and speed of habitat surveys in categorising vegetation (compared with e.g. Joint Nature Conservation Committee Phase 1 surveying), understanding how different livestock grazing species utilise different areas and patches of vegetation, or investigating how management techniques such as grazing, cutting or burning alter the structure of a vegetative community.

Keywords: remote sensing, classification, vegetation composition, surveying, imagery

Introduction

Traditionally, vegetative patterns within semi-natural grasslands have been assessed using laborious field sampling methods, which are impractical on landscape-scale studies. Increasingly remote sensing techniques, particularly space-borne imagery, are becoming a more accepted method to classify vegetation. Though commercial satellites or multi-temporal public data sets, such as Worldview or the Landsat Thematic Mapper satellite system (Knoth *et al.*, 2013) are increasingly achieving higher resolutions (e.g. Worldview 3 being capable of ~1.24 m resolution for multispectral imagery), they are inhibited by cloud cover, the length of time between image acquisitions (16 d for Landsat), and high costs when using multiple image acquisitions (e.g. from different time points) (Anderson and Gaston, 2013). They are, therefore, often unsuitable for monitoring within-season variations in vegetation change, and subsequently, are of limited use in studies assessing the effects of management techniques on vegetation, such as cutting, burning or grazing. Unmanned aerial vehicles (UAVs), however, can provide up-to-date imagery at higher temporal, spatial and spectral resolution then satellite-based imagers (< 1 m per pixel resolution) (Eisenbeiss and Sauerbier, 2011). They can be deployed where and when needed as they are operated below cloud level and therefore, provide the necessary flexibility to perform frequent observations which may be used to monitor short-term changes in vegetation; be it seasonal or as a result of management techniques. Fixed wing UAVs, in particular, are capable of long flight times (< 1 h), and therefore, are capable of surveying large sites extending to hundreds of hectares. This study summarises the effectiveness of using multispectral imagery achieved from a low-cost UAV platform to classify vegetation types found at upland sites in mid Wales.

Materials and methods

The UAV set-up was similar to that of Ryan *et al.* (2015). The UAV airframe was a publicly available Skywalker X8 (Skywalker; Hubei, P.R.China) Autonomous flight capability was used (http://ardupilot.com): this provided flight stabilisation; altitude control and GPS navigation. A red-edge multispectral camera (MicaSense; Seattle, USA) was mounted on the underside of the airframe, facing nadir (90 degrees to the ground). The red-edge is a multispectral imager with five sensors at 1.6 megapixel resolution; red (R); green (G); blue (B); near-infrared (NIR) and Red-Edge (RE). It featured an attachable GPS sensor to enable image geotagging, as well as a combined magnetometer/downward light sensor (DLS) (MicaSense; Seattle, USA) to record angles during image capture and solar irradiance throughout the image run. Combined with image captures of a supplied calibrated reflectance panel (CRP) before and after each image run, this provided necessary data for atmospheric correction. The capture trigger mode was set to overlap (automatically takes captures within 50 m of target altitude, and calculates distance between each capture to ensure > 75% overlap). Flight height was set to 120 m. 'Atlas' (MicaSense; Seattle, USA) was used to stitch the imagery and produce georeferenced orthomosaics used for classification. These orthomosaics were subsequently processed using the RSGISLib open source software library (http://www.rsgislib.org). Vegetation classification was performed using a supervised pixel based script incorporating the scikit-learn (machine learning library) random forest classifier. Training samples for different vegetation in each site were created in QGIS (ver 2.18.10 'Las Palmas'). A band stacked image including ratio transformations between all five bands was used as the input image, along with NDVI (Normalized Difference Vegetation Index), and WBI (Water Band Index) inputs. The generated classification was subsequently clumped to remove speckling caused by high local spatial heterogeneity between neighbouring pixels. Sampled areas on site were ground-truthed to check classification accuracy.

Results and discussion

Results using unprocessed raw images found the pixel (pxl) resolution to be ~ 8 cm^2 pxl^{-1}. During image processing for vegetation classification, 0.5 m pxl^{-1}, and 1 m pxl^{-1} image inputs achieved through pixel binning (procedure of combining a cluster of pixels into a single pixel) were analysed and compared against the full resolution input image. For this study, the optimum size was found to be 0.5m pxl^{-1}, while allowing for minimising the impact of read noise on the processed image, and retaining sufficient resolution not to exclude small vegetative patches or miss-classify known samples. Therefore, all subsequent imagery for classification was analysed using 0.5 m pxl^{-1} resolution. When compared alongside previous UK Joint Nature Conservation Committee Phase 1 maps similar classifications were noted, however, there were less hard edges between classifications in the UAV imagery, with a number of boundaries between classification blocks seeing a heterogeneous mixture of classifications. This raises a consideration that UAV imagery may provide important data regarding the 'grey areas' between vegetation classifications not found in Phase 1 surveys. At full resolution, a number of potential features of interest, such as animal pathways were clearly distinguishable which could be used in future studies. Also noted on the images from one site were distinct vegetative patches (Figure 1) which were confirmed to match locations of patches mown 26 months previously. Whether a legacy from cutting, or a result of subsequent sheep grazing; this information outlines key areas for future work.

Conclusion

This study has shown that multispectral imagery from UAVs could offer an alternative methodology for classifying and monitoring vegetation change across large sites in inaccessible locations. However, the requirements of the classification must be considered carefully with regard to the research question posed and nature of the site assessed (e.g. level of heterogeneity within mosaics).

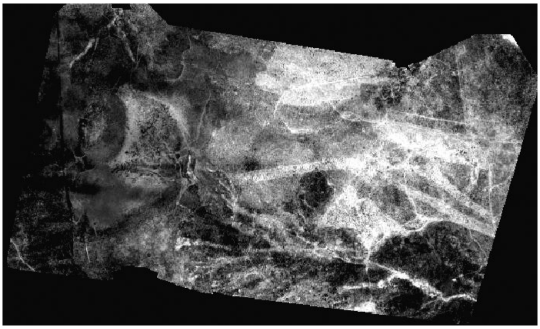

Figure 1. Normalised difference vegetation index (NDVI) of 69 ha of *Molinia caerulea*-dominated grassland. Bright sections on the right-hand side of image match previously cut areas.

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LiDAR-based estimation of extensive grassland biomass invaded by large-leaved lupine (*Lupinus polyphyllus* Lindl.)

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Abstract

In recent decades, the invasive neophyte *Lupinus polyphyllus* Lindl. has challenged extensive and species rich grassland ecosystems in Europe, e.g. within the UNESCO biosphere reserve Rhön. Its ability for nitrogen fixation and phosphorus mobilisation is a threat to biodiversity. To prevent a further spread of *L. polyphyllus*, appropriate management procedures are necessary. Remote sensing as a tool for early detection of *L. polyphyllus* and the estimation of its biomass plays a decisive role. Biomass estimation of extensive grasslands extracted from Terrestrial Laser Scanning (TLS) measurements is rarely investigated. A range of TLS measurements within an area, of which one subsection was dominated by oatgrass and the remainder by matgrass, were taken between May and September 2016. LiDAR-based parameters were evaluated for their potential to estimate total biomass (fresh and dry). Four variables were chosen: (1) Canopy Surface Height (CSH), (2) Sum of Voxels, (3) Volume of Convex-Hull, and (4) Point Density. The strongest models for total biomass prediction were achieved by CSH and Sum of Voxels. All models showed better prediction accuracies for fresh biomass compared to dry biomass. To improve the methods for non-destructive lupine biomass estimation, additional measurements with hyperspectral sensors could highlight differences between plant species. Furthermore, the use of Mobile Laser Scanning (MLS) could increase the size of the sample areas.

Keywords: above-ground biomass, LIDAR, TLS, Voxel-Sum, Convex-Hull, remote sensing

Introduction

To prevent erosion and enrich the soil with elementary nitrogen and phosphorus from deeper soil layers, *Lupinus polyphyllus* was used in new plantations of spruces. Therefore, in the 1940s *L. polyphyllus* was introduced to the Rhön, a low mountain range in central Germany, at the borders of the states of Hessen, Thuringia and Bavaria. This, and later anthropogenic interventions allowed the lupine to expand into nature protection sites of the biosphere reserve in Rhön. As a result of this invasion, not only floral components changed, but also the ground-breeding birds black grouse and corn crake lost their preferred habitat structure (Volz, 2003). *L. polyphyllus* contains high levels of alkaloids and, therefore, also has potential to endanger the health of grazing animals (Düll, 1988).

To manage this invasive species, an early detection and quantification of *L. polyphyllus* is necessary. The potential of terrestrial laser scanning (TLS) lies in its three-dimensional point clouds that provide structural parameters for biomass estimation. To date, this technique is mostly used in forestry (Calders *et al.,* 2015), and the research of grassland biomass estimation by TLS systems is still at the initial stages.

Materials and methods

Fieldwork was carried out at two sites in the area of the Rhön biosphere reserve. TLS measurements of a matgrass (*Nardus stricta*) site (ca. 50° 28' 3'' (N), 10° 1' 37.6'' (E)) and an oatgrass (*Trisetum flavescens*) site (ca. 50° 28' 49'' (N), 10° 2' 38'' (E)) were conducted. Each site had three plots of 8 × 8 m which were sampled on 25 May 2016, 13 June 2016 and 12 September 2016. The coordinates of the corners of each plot were determined in spring (04 May 2016), while the plots were scanned with and without marginal vegetation in order to provide a digital elevation model (DEM) of the soil surface. At each measurement, the plots were divided into 1 m^2 sub-plots and three of these sub-plots were selected randomly from each plot at each date. The biomass of sub-plots was sampled by manual clipping. This resulted in a dataset of 45 measurements in total. In addition to the fresh biomass, all samples were dried at 105 °C for a min of 48 h and the dry biomass was measured. Before sampling, each plot was scanned by a Leica Scan Station P30 (pulse laser) from four sides to reduce the effect of occlusions. For spatial reference, three highly reflective targets were mounted on tripods around the plot.

Raw data was imported to Cyclone 9.1 (Leica) and exported as merged point clouds. For calculations in R-Studio, the datasets were divided into 1 m^2 sub-plots and separately stored for a faster work flow. Thus, each measured biomass value had a corresponding 1 m^2 point cloud. Four categories of variables were chosen for total ground biomass estimation: (1) Canopy Surface Height (CSH), (2) Sum of Voxels, (3) Volume of Convex-Hull, and (4) Point Density. Canopy Surface Height defines a height value for each point inside the point cloud derived by the digital elevation model (DEM) created in spring. Mean values were calculated for multiple height sections, e.g. the top 25% of all points, and then checked for correlation with total dry and fresh biomass. The Sum of Voxels subdivides a point cloud into voxels (volumetric pixels) with an arbitrary defined size. Every voxel with a minimum of one point inside is added to the sum of voxels, which is checked for correlation with total dry and fresh biomass. The Volume of Convex-Hull is calculated with the quickhull algorithm (Barber *et al.*, 1996). A line is drawn between the point with the highest and the lowest x-value of the point cloud, then on both sides of the line, the point with the highest distance to the line is determined and used to create a triangle. Ignoring all points inside the triangle, the point with highest distance to the new lines is used to create another triangle, which is added to the already existing one. When all points are included, the generalised area and volume of the Convex-Hull is computed and checked for correlation with total dry and fresh biomass. The Point Density method derives point density mean values in multiple point heights by dividing the point cloud with a three-dimensional grid. The points counted for each grid cell were computed and averaged, including all points located between the 25 and 50% quantile of their CSH values, the points between 50 and 75%, those between 75 and 100% and, eventually, all points over the whole CSH range were calculated and checked for correlation with total dry and fresh biomass. The dependent variables (total fresh biomass and total dry biomass) were checked for normal distribution by using the Shapiro-Wilk test. Fresh and dry biomass values had to be log-transformed to achieve normal distribution.

Results and discussion

Best linear models for fresh total biomass resulted from using the CSH-method from height section 95 to 100% with an adjusted R^2 of 0.72 and from the method 'Sum of Voxel' with a voxel edge length of 4.5 cm (R^2 = 0.69) (Figure 1). To guarantee a model stability for 'Sum of Voxel', the best model was chosen at a saturation point of min 1% R^2 increase. In all cases, models for dry total biomass estimation had less explanatory power than those for fresh total biomass. This was expected, due to the nonlinear relation between plant habitual properties and plant water content. Canopy Surface Height performed well and equal to Voxel-Volume. Voxel-Volumes was confirmed as a powerful predictor for biomass estimation, as demonstrated by Olsoy *et al.* (2014) and Greaves *et al*. (2015).

Conclusion

As a non-destructive method, terrestrial laser scanning provided promising results for estimation of matgrass and oatgrass biomass. Optimised model stability through data expansion is necessary for implementation in practical tasks. The static TLS system needs to be enhanced to overcome its need for financial and time resources, in order to be applicable in nature conservation practices. Furthermore, additional measurements with hyperspectral sensors could highlight differences between plant species and therefore, may help to classify and quantify *L. polyphyllus*.

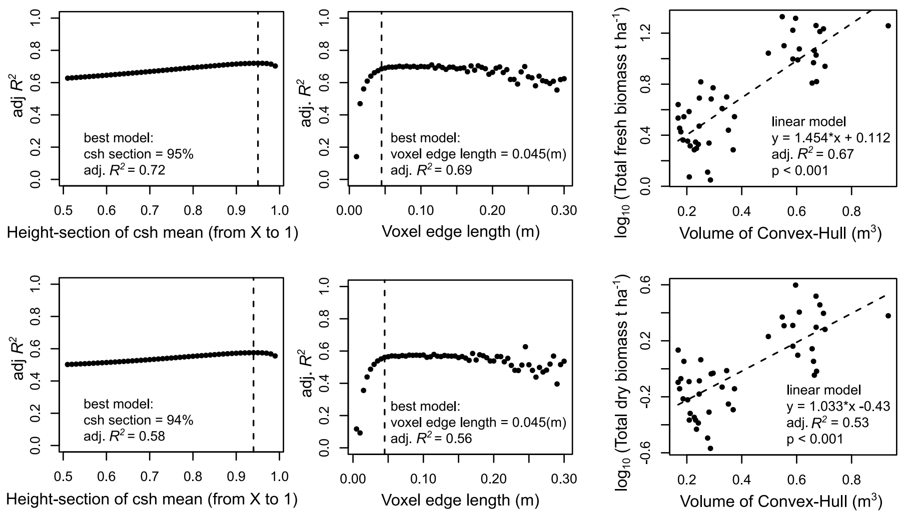

Figure 1. Linear models for variations of the canopy surface height (CSH)-method, the Voxel-Sum-method and one linear model for Convex-Hull with each fresh and dry total above-ground biomass.

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Traceability of pasture milk: how much maize are the cows fed?

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Abstract

Pasture milk is gaining importance on the milk market. Dairy companies set rules for the minimal daily time animals should spend on pasture and for the number of pasture days. However, the amount of fodder to be taken up from grazing on pasture or the percentage of grass in the cow diet is not specified any further. Here, we show results of a screening study carried out in May 2017, where carbon isotope signatures of milk from farmers with known feeding regimes were related to the amount of maize (C4 plant) in the ration. Then, δ^{13}C-signatures of milk samples from the market declared as pasture milk, organic milk or not further specified (conventional milk) were investigated and the amount of C4-plants in the ration calculated. Moreover, discrimination analysis was used to attribute milk sample ^{13}C and ^{15}N signatures to feeding regimes. Results indicate that the average calculated amount of maize in the ration was smallest in organic milk (32%), intermediate in pasture milk (44%) and largest in conventional milk (49%). This suggests that animals producing pasture milk are fed a noticeable amount of maize, even at a time of the year with favourable pasture conditions.

Keywords: stable isotopes, ^{13}C, maize/corn, screening, ^{15}N

Introduction

The feeding regime of dairy cows has important effects on the composition of their milk. Unsaturated fatty acids and other components considered valuable for human nutrition have been especially related to the amount of fresh grass in the animals' diets (Elgersma *et al.*, 2006). Together with consumers' concerns for animal health, this has led to the establishment of pasture milk labels. This milk is usually specified by the amount of time the animals spend on pastures per day (often at least 6 h) and per year (often minimally 120 d). However, the amount of fodder grazed on pasture is not considered. This might lead to differences concerning the amount of fodder offered in the stable and the amount of fodder animals are willing to graze on pasture. Here, we used stable carbon isotope analyses of milk samples declared as conventional, organic, or pasture milk to compare the amount of maize in the respective rations.

Materials and methods

Between 07 May and 23 May 2017, milk samples were collected from local dairy farms (n = 7) with known feeding regimes and from packaged consumers' milk from different companies purchased in shops (n = 25). Local farms were chosen with a view to a diversity of production and feeding systems, and farmers reported feeding 21 - 70% maize in the ration. Milk from the shops included ten organic labels, 5 labelled as pasture milk and ten further unspecified samples (conventional milk).

Samples were frozen until further analysis. Complete milk samples were then freeze-dried (two - three days at -80 °C) and the lyophilisate analysed for ^{15}N and ^{13}C on an elemental analyser (varioPYROcube) coupled to an isotope ratio mass spectrometer (Isoprime 100). Results are shown in δ notation, calibrated against the international standards VPDB for ^{13}C and air for ^{15}N. Based on the linear regression between the δ^{13}C signatures of milk samples collected from dairy farms and the amount of maize in their ration, we derived the amount of maize fed in the rations of cows that produced the shop milks, using their δ^{13}C values. A discrimination analysis was used for discriminating between feeding regimes based on both ^{13}C and ^{15}N signatures. Statistics were calculated with SPSS and R (R Development Core Team, 2017) ($\alpha < 0.05$).

Results and discussion

As expected, there was a significantly positive correlation between $\delta^{13}C$ values and the amount of maize in the ration of sampled dairy farms ($P = 0.004$; $r^2 = 0.836$). Maize as a C4 plant has a more enriched ^{13}C signature compared with C3 plants, and as milk has been shown previously to mirror the forage taken up by the dairy cows, a larger contribution of maize to the diet leads to the observed more enriched values (Knobbe *et al.*, 2006).

The C isotopic signatures were significantly more enriched in milk from conventional than from organic production ($\delta^{13}C$ = -23.03 ± 1.71‰ and -27.18 ± 1.28‰ for conventional and organic, respectively). Milk declared as pasture milk had intermediate signatures ($\delta^{13}C$ = -24.31 ± 1.61‰). This led to calculated amounts of maize in the ration being highest for conventional milk, intermediate for pasture milk and lowest for organic milk (Figure 1). The relatively large ranges are interesting and show the varying feeding regimes within each category, but especially for pasture milk.

The discrimination analysis highlighted the large variation in $\delta^{13}C$ compared to $\delta^{15}N$ values. Based on $\delta^{13}C$ values, organic and conventional milk could be differentiated by discrimination analysis, with a threshold $\delta^{13}C$ signature of -25.5‰ that led to a correct classification of 85.7% of the conventional milk and 90.9% of organic milk samples in this study. Pasture milk could not be discriminated from the other two categories based on these data. This shows that the amount of C4 plants in the diet differs between organic and conventional milk, but not strongly enough between pasture milk and the other categories.

The data show that concerning the feeding regime, pasture milk seemed to be more similar to conventional milk than to organic milk. Of course, the $\delta^{13}C$ signature only gives an indication of the amounts of C3 and C4 plants in the ration. The C3 part is not necessarily taken up on pasture, but could also be grass silage, for example. We calculated that the dairy cows producing pasture milk received on average about 44% of maize in the ration, even at a time (May) when pasture conditions should have been good.

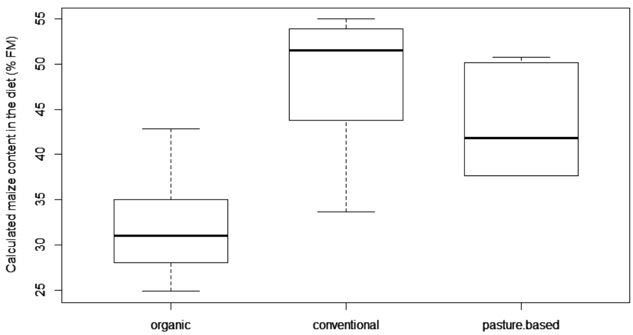

Figure 1. Calculated percentage of maize in the ration of cows producing organic (n = 10), conventional (n = 10), or pasture (n = 5) milk.

Conclusion

In this study, dairy cows producing pasture milk tended to receive less maize in the ration than conventional cows. The amount of maize in the rations of dairy cows producing pasture milk varied from 37 to 51%. Although a discrimination between organic and conventional milk was possible based on $\delta^{13}C$ data, the fodder of cows producing pasture milk was, on the one hand, too similar to the other two categories and, on the other hand, too variable within this category, to be differentiated based on $\delta^{13}C$ signatures alone.

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Nutrient transfer by cattle through different spatial patterns of grazing and non-grazing behaviour

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Keywords: GPS telemetry, nutrient transfer, phosphorus, potassium, animal behaviour

Introduction

Grazing animals may be associated with nutrient transfer when various factors influence spatial preferences for grazing and non-grazing activities. We investigated sward structure, soil nutrient concentration and spatial patterns of grazing and non-grazing behaviour, and their impact on soil nutrient concentrations in a 15-year-old cattle grazing experiment with three grazing intensities, in which patch grazing had led to the development of a stable mosaic structure of short and tall patches. We expected a relationship between measured soil nutrient concentrations and nutrient transfer pattern predicted from animal GPS telemetry.

Materials and methods

One animal on each of the 9 × 1 ha paddocks of the experiment was fitted with a GPS and activity sensor for 28 days. Behaviour (grazing / non-grazing) was predicted from sensor data based on direct animal observations. A nutrient transfer index (NTI) was calculated as the difference between the relative density of all animal locations and the relative density of animal locations classified as 'grazing'. A remote sensing image was used to assess whether animal locations were situated in short or tall sward areas. Per paddock, 30 soil samples (0 - 10 cm) were taken in short and tall sward areas and analysed for their concentration of calcium-acetate-lactate (CAL) extractable P and K. The effect of sward structure on the location of animals during grazing and non-grazing behaviour was analysed using poisson point process models. Linear mixed effects models were used to assess the effect of sward structure, grazing intensity and NTI on soil P and K concentrations.

Results and discussion

Cattle were located in short patches more often when grazing than when not grazing. Non-grazing behaviour showed very marked concentrations in hotspots that were probably related to animal social behaviour across paddocks. The CAL-P and -K in soil were higher in tall compared to short sward areas (P: 67 vs 40 mg kg^{-1}, K: 228 vs 135 mg kg^{-1}). There was a strong relationship between soil CAL-P and -K and the animal-mediated nutrient transfer predicted from behaviour data (NTI).

Conclusions

Patch-grazing and spatial concentration of non-grazing-behaviour preferences had a marked influence on soil nutrient concentrations in a 15 year old low-intensity cattle pasture. Results indicate that even on relatively small paddocks, nutrient transfer processes can strongly affect pasture fertility.

Comparison of two non-destructive techniques to determine DM yield in the tropics

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Abstract

Dry matter yield determines both stocking rate and animal carrying capacity on farms, but to estimate such indicators, accurate yield measures are required. Some common techniques to estimate biomass in pastures are cumbersome, which makes producers reluctant to undertake measurement. In temperate grazing systems, use of plate meter devices has improved frequency of measurement. However, plate meter calibration equations were developed with temperate grasses (i.e. ryegrass, fescue, etc), and their use in the tropics thus far is limited and has not been evaluated. In this study, we estimated biomass across one year with both the Botanal® technique and a rising platemeter in Costa Rica, focusing on perennial ryegrass (*Lolium perenne*), Kikuyu (*Kikuyuocloa clandestina*), and African Stargrass (*Cynodon nlemfuensis*) pastures. Estimates of DM yield made with a plate meter were higher than with the Botanal® technique, especially in ryegrass (1,553 kg DM ha^{-1}), but also in Kikuyu (720 kg DM ha^{-1}) and Stargrass (683 kg DM ha^{-1}) pastures. Calibration of the plate meter with the regression equations developed in this study may improve accuracy with grasses grown in the tropics. Such straightforward techniques for biomass estimation could improve adoption by producers on tropical farms.

Keywords: ryegrass, Kikuyu, Stargrass, yield, platemeter, Botanal

Introduction

Livestock operations require accurate estimates of biomass yields as a means to allocate DM to grazing cattle. Livestock producers and technicians use estimates of the DM available in paddocks to make decisions related to stocking rates, rest periods, grazing intensity and nutritional balances. Many methods are available to estimate DM yield, which can be categorised as either destructive or non-destructive. Destructive techniques include the partial or total harvest of a significant area of the paddock or field, generally using machinery. Non-destructive methods extrapolate estimates from a small sample to a larger area.

The Botanal® is a non-destructive technique that combines hand-clipped and observational samples. Unfortunately, given that the clippings must be dehydrated for 48 h at 60 °C before an estimate can be calculated, many producers choose not to measure biomass with this technique. Plate meters, on the other hand, are devices that estimate biomass by applying pre-calibrated regression equations based on pasture height and density. Because plate meters provide data *in situ*, producers are more prone to use them as compared to other methods. However, the accuracy and precision of calibration equations of rising plate meters have not been evaluated with grass species in the tropics. In this study, we compare DM yield estimates using the rising plate meter and Botanal® techniques with ryegrass, Kikuyu, and African Stargrass in Cartago, Costa Rica.

Materials and methods

Dry matter yield of perennial ryegrass, Kikuyu and Stargrass, was measured at three dairy farms located at 2,800, 2,400 and 1,400 m elevation, respectively. In 18 pastures of each species, on the day before grazing, biomass was estimated using two techniques: (1) AgHub™ F300 electronic rising plate meter and (2) Botanal®. Plate meter measurements were taken first to avoid interference due to walking or clipping during Botanal® sampling. The plate meter was used with the pre-calibrated equation regression 'y = 140 + 500x', and 30 - 40 observations were taken in paddocks with an average area of 3,140, 1,533, or 4,188 m^2 for ryegrass, Kikuyu or Stargrass, respectively.

During Botanal sampling, three levels of grass were collected that combined height and density (1 = low, 2 = medium, and 3 = high), hand-clipping each in a randomly placed 50 cm × 50 cm metal frame and drying in an air-forced oven at 60 °C for 48 h in the Research Centre for Animal Nutrition at the University of Costa Rica. In addition, 50 observations of level were taken in a zig-zag pattern. Then, the dry mass of the three levels were incorporated along with the observations, to estimate kg DM h^{-1} using the Botanal spreadsheet. Pasture slope was also measured with a nivelometer, and average sward height was measured with the plate meter.

To compare the relative accuracy between the two methods, the differences in estimated biomass were calculated. Regression equations were also developed for the three species based on the intercepts and slopes of Botanal estimates. These latter were estimated by weighting the average level in the paddock (50 observations) against the dry biomass from each level. Finally, the average level in each pasture was estimated using the calculated regression equations, and compared biomass estimates directly from the Botanal with those of the calculated regression outputs.

Results and discussion

Biomass estimates were higher with the plate meter than with the Botanal in all three species (Table 1). Ryegrass and Kikuyu pastures had similar yields with the Botanal method. Stargrass pastures exhibited the greatest yields with both methods. These results are similar to previous evaluations of biomass using the Botanal technique in ryegrass and Kikuyu pastures (3,360 and 3,517 kg DM ha^{-1}, respectively), but are greater in Stargrass (3,185 kg DM ha^{-1}) (Villalobos *et al.*, 2013). The differences found between the plate meter and Botanal techniques were greater in ryegrass as compared to Kikuyu and Stargrass (Table 1). Here we found a minimum of 13% difference between estimates in all species, suggesting that further calibrations are necessary to improve accuracy, because other studies note that 10% is a maximum acceptable difference relative to Botanal or other hand-clipping techniques (Sanderson *et al.*, 2001). The slope was steeper in ryegrass and Kikuyu paddocks than in Stargrass (Table 1). Swards were taller in Stargrass than in ryegrass or Kikuyu pastures.

Biomass estimates obtained with regression equations were similar to those obtained with the Botanal (Table 2); Stargrass had the greatest yield, followed by Kikuyu and ryegrass. The average differences between the regression equations and Botanal were greater for Stargrass followed by ryegrass and Kikuyu.

Table 1. Biomass yields of perennial ryegrass, Kikuyu and Stargrass estimated with two non-destructive methods in the highlands of Costa Rica.

Variable	Ryegrass		Kikuyu		Stargrass	
	Botanal	Plate meter	Botanal	Plate meter	Botanal	Plate meter
Average biomass (kg DM ha^{-1})[1]	3,368	4,922	3,493	4,462	5,399	6,083
Difference (plate meter-botanal)[2]	1,553 ± 217 (118-3,394)		720 ± 330 (-3,860-2,831)		683 ± 272 (-1,168-2,896)	
% difference[3]	46		21		13	
Slope in the pastures (%)	14.4 ± 3.0		11.9 ± 3.7		3.3 ± 0.9	
Sward height (cm)	31.5 ± 1.1		28.8 ± 0.8		40.0 ± 0.8	

[1] n = 18 paddocks per species.

[2] Standard error and range (min-max).

[3] (plate meter - botanal)/botanal × 100.

Table 2. Estimated biomass yields for perennial ryegrass, Kikuyu and Stargrass with an equation regression and their respective differences in the highlands of Costa Rica.

Variable	Ryegrass	Kikuyu	Stargrass
Regression equation for each species	y = -193 + 1,675x	y = -299 + 2,164x	y = 88.7 + 2,426x
Estimated biomass, kg DM ha^{-1}	3,400	3,519	5,311
Average difference (regression - botanal)[1]	32.1 ± 240 (-1,652-1,685)	25.7 ± 230 (-1,872-1,924)	-88.3 ± 217 (-1,715-1,532)

[1] Standard error and range (min - max).

Conclusion

In previous studies, researchers have found that non-destructive techniques using universal equations are likely to require calibration because grazing conditions vary among climatic regions. The existing equations for the plate meter had not yet been evaluated with grasses in the tropics but results from this study suggest that with calibration, this device could be beneficial for producers in estimating biomass in tropical pastures. The regression equations developed in this study can be uploaded to the rising plate meter and again compared to the Botanal method to further improve accuracy.

Acknowledgements

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Validation of new algorithms for the RumiWatch noseband sensor to detect grazing behaviour of dairy cows

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Abstract

Grazing behaviour is an important indicator of cow health and grazing management. As herd size increases and labour availability decreases, monitoring of grazing behaviour of individual animals may be supported by automated sensors. Therefore it is crucial that the automated systems can measure grazing behaviour accurately. The RumiWatch noseband pressure sensor records each cow jaw movement. The RumiWatch Converter is the software package used to convert the pressure sensor data into grazing behaviour variables using generic algorithms. Grazing bites, rumination chews, grazing and rumination times can be accurately discerned. A new version of this RumiWatch Converter has now been developed based on more recent grazing behaviour measurements. This latest version (V.0.7.4.10) and the previous version (V.0.7.3.36) were tested against human observation to assess agreement and accuracy. Preliminary analysis showed a 5% increase in the overall accuracy in detection of the correct behaviour for version V.0.7.4.10 at a 1 min resolution compared to the previous version V.0.7.3.36. The correlation between automated and manually recorded grazing time was higher for V.0.7.4.10 with rs = 0.97 compared to rs = 0.91 for V.0.7.3.36 at a 1 h resolution. In conclusion, the development of new algorithms in the RumiWatch Converter V.0.7.4.10 increased the accuracy for detecting grazing behaviour at the 1 h resolution.

Keywords: noseband pressure sensor, algorithms, data analysis, grazing behaviour

Introduction

The development of affordable, reliable, and robust sensor-based technology is ongoing. As herd size increases, and labour availability on dairy farms decreases, using sensors can aid in monitoring animals continuously and automatically. Grazing behaviour is a particularly important indicator of health and welfare of a dairy cow (Bareille *et al.*, 2003). Additionally, grazing behaviour is an important indicator for grazing management (e.g. indicator for insufficient grass allocation; Werner *et al.*, 2017a). However, most sensor technology developed for dairy farms have been designed for indoor feeding. Feeding behaviour of cows on grass differs, thus sensors need to be appropriately calibrated. In a previous study by Werner *et al.* (2017b), the RumiWatch noseband sensor was validated against visual observation in an intensive pasture-based milk production system. A high accuracy was detected for measuring grazing and rumination times at 1 min and 1 h resolutions. However, in following studies, a lower accuracy was detected around milking times and when cows were leaving the paddock. It is hypothesised that walking may influence the accuracy of the noseband sensor in detecting grazing time. Therefore, the RumiWatch Converter, the software to analyse the data, was adapted in an attempt to increase the accuracy of data recording while cows are walking. The objective of this study was to compare the previous version of the RumiWatch Converter V.0.7.3.36 against the newly developed version V.0.7.4.10. Visual observation was conducted as the reference method on a spring calving dairy herd.

Materials and methods

The experiment was conducted at the Teagasc, Animal and Grassland Research Centre, Moorepark, Fermoy, Co. Cork, Ireland during the period of 31 March to 19 April 2017. The research farm had a herd of 84 cows milked in an automatic milking system (Lely Astronaut A4, Lely, Maassluis, the Netherlands) with a 4-way grazing system. Nineteen spring calving dairy cows of the herd were equipped with the RumiWatch noseband sensor. Cows had an average days in milk (DIM) of 46 ± 17 and an average milk yield of 24.4 ± 9.5 kg cow^{-1} day^{-1} at the beginning of the experiment. All cows were pluriparous Holstein-Friesian and were maintained on a pasture diet with concentrate supply at the robot (< 3 kg $milking^{-1}$) with on average 1.5 milkings day^{-1}. Visual observation was conducted by 6 trained observers over 2 × 3.5 h periods per day for 12 days during the 20 day experimental period. Four observers recorded cow behaviour simultaneously, with two of the observers monitoring 2 cows and alternating after 30 min slots. Behavioural classifications of grazing, rumination and other activities were recorded continuously over each 30 minute period per observer using a smartphone application. The application recorded timestamps for each behaviour, started or finished. The continuous data were then processed to categorize the behaviour type in each minute and totalled the time durations in 1 h periods.

The RumiWatch halter recorded raw data with a 10 Hz resolution. This raw data was converted by the RumiWatch Converter V.0.7.3.36 (V.3) and RumiWatch Converter V.0.7.4.10 (V.4) into 1 min and 1 h summaries. Visually recorded and automatically measured data were then analysed using agreement statistics. Statistical analysis was performed using R version 3.3.1 (R Foundation for Statistical Computing, Vienna, Austria), with Cohen's Kappa and Percentage agreement *(PA) = (total numbers of agreement)/(total numbers of agreement + total numbers of disagreement) × 100* used for categorical 1 min summaries. The Concordance Correlation Coefficient (CCC), Spearman's Rank Correlation Coefficient (rs), and Bland-Altman-Analysis were calculated for 1 h summaries.

Results and discussion

Results of statistical analysis of categorical data at 1 min resolution are presented in Table 1. The newer converter (version V.4) showed a better overall performance with Cohen's Kappa (κ) value of 0.83 and PA = 89.7% compared to V.3 with κ = 0.76 and PA = 84.9%. However, accurate and detailed classification of grazing and rumination at a 1 min resolution was reduced with V.4 compared to V.3. Alternatively, the correct classification of other activities (all activities other than grazing and ruminating) increased. The correlation of V.4 in measuring time spent grazing in a 1 h resolution was high with rs = 0.98 and CCC = 0.98 compared to rs = 0.91 and CCC = 0.95 for V.3, respectively (Table 2). Also, the Bland-Altman-Analysis demonstrated a higher accuracy for recording grazing time with V.4 (Table 2). The mean bias for rumination time was 0.34 min h^{-1} and 0.47 min h^{-1} for V.4 and V.3, respectively. In comparing the performance of the new to the older converter, a slightly complex picture emerges. In general the new

Table 1. Cohen's Kappa (κ) and percentage agreement between visual observations and automated measurements by RumiWatch with two RumiWatch Converter versions (V.4 and V.3) for grazing, rumination and other activities in a 1 min resolution.

	Cohen's κ	Overall agreement between visual and automated measurement (%)	Classification	Agreement between visual and automated measurement (%)
V.3 vs visual	0.76	84.9	grazing	93.1
			ruminating	92.5
			other activities	70.8
V.4 vs visual	0.83	89.7	grazing	90.4
			ruminating	90.9
			other activities	88.1

Table 2. Spearman's rho (rs), Concordance Correlation Coefficient (CCC), and Bland-Altman-analysis (Bias, upper and lower 95% limits of agreement) of automated measurements versus visual observations in a 1 h resolution for different behaviour classifications.

		rs	CCC	BIAS	UPPER	LOWER
Grazing	V.3 vs visual	0.91	0.95	5.94	18.61	-6.72
	V.4 vs visual	0.98	0.98	2.28	10.32	-5.75
Rumination	V.3 vs visual	0.98	0.94	0.47	5.89	-4.96
	V.4 vs visual	0.97	0.93	0.34	6.14	-5.45
Other Activities	V.3 vs visual	0.87	0.96	-6.43	5.77	-18.63
	V.4 vs visual	0.97	0.98	-2.62	4.57	-9.81

converter performs better having higher accuracy, in particular for hourly summaries. However, at the minute by minute level, the older converter was more accurate for measuring grazing and rumination time. The increased accuracy in recording grazing time at 1 h resolution may be due to the fact that the algorithms are developed for 1 h resolution measurements rather than 1 min resolution. However, the 1 min resolution is valuable for research purposes, to assess treatment effects or behavioural changes in a small time resolution. Various sensors are limited in data recording to summaries of 10 or 15 min.

Conclusion

The overall accuracy of the V.4 for all activities (grazing, rumination and other activities) was higher than the V.3 at a 1 min resolution. However, when V.4 was applied to the individual classifications, V.3 was more accurate for grazing and rumination at the 1 min resolution. Alternatively, the V.4 was more accurate at the 1 h resolution. The results demonstrated that V.4 has a higher accuracy in detecting grazing and rumination behaviour than V.3 when using the automated measurement to record these activities at 1 h resolution.

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Estimation of yield and height of legume-grass swards with remote sensing in Northern Sweden

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Abstract

The arable land in northern Sweden is dominated by forage crops, which are a mixture of legumes and grasses. The yield and height of a forage crop are important agronomic variables for management. In this study, an ultrasonic sensor used to estimate sward height (SH) and a hyperspectral radiometer used to estimate DM yield, represented rapid methodologies to measure agronomic variables in the field. In 2017, plant sampling was carried out at multiple locations and dates in Northern Sweden. At each sampling location, estimation of SH by ultrasonic sensor and ruler, and canopy reflectance by spectrometer were carried out on a marked circular plot of 0.25 m^2. The observed SH from manual measurement was highly correlated with estimated SH by ultrasonic sensor (R^2 = 0.86). Partial least square regression (PLSR) was used to estimate forage dry matter yield. The performance of PLSR showed satisfactory results with relative root mean square error of 12%.

Keywords: ultrasonic sensor, plant height, partial least square regression

Introduction

In northern Sweden, perennial forage crops (legume and grass mixtures) dominate 79% of arable agricultural land (SCB, 2017). Forage yield is an important agronomic variable for feed budgeting and evaluation of management decisions. The conventional method for yield determination is plant sampling, which involves destructive plant clipping, drying and weighing of samples. The precision of this method is low due to the heterogeneity of fields. The method is also time consuming and likely to result in time delay in decision making. Alternatively, canopy spectral reflectance measurement by hyperspectral or multispectral radiometer has been evaluated and show high potential to estimate forage yield (Biewer *et al.,* 2009).

Crop height is also important for decision making, as it is closely related to other agronomic variables such as leaf area index and yield (Ehlert *et al.*, 2008). The most common method used by agronomist and plant breeders to measure crop height is with a meter stick, which is time consuming. Alternatively, remote sensing methods have been proposed to estimate crop height, e.g. laser and ultrasonic sensors. Using ultrasonic sensors to estimate canopy structure characteristics is a new research area (Fricke and Wachendorf, 2013), especially for measuring forage height. Therefore, the objectives were (1) to estimate forage DM yield with hyperspectral reflectance; (2) to test the applicability of an ultrasonic sensor to estimate forage height.

Materials and methods

The research was carried out in 2017 at three sites in northern Sweden: Robacksdalen research station (63.81 N, 20.24 E), Öjebyn (65.36 N, 21.39 E) and Ås (63.25 N, 14.56 E). Areas of forages with mixtures of red clover (*Trifolium pratense* L.) and timothy (*Phleum pratense L.*) were chosen for sampling. Each plot involved an area of 0.25 m^2 on which measurements of canopy spectral reflectance and ultrasonic height were conducted. Subsequently, the sward within the plot was clipped for DM determination. The process was carried out between 20 June and 17 August 2017, corresponding to the typical period of first and second cutting as managed by farmers. In total, 86 plots were measured. Canopy height was measured by ruler and ultrasonic sensor (UC 2000-30GM-IUR2-V15, manufactured by Pepperl and Fuchs, Mannheim, Germany). Canopy spectral reflectance measurement was conducted with a Yara N-sensor spectrometer (Yara International ASA, Oslo, Norway). The field spectrometer measures canopy spectral reflectance at wavelength of 400 - 1000 nm with resolution of 10 nm.

The original spectral data was transformed by standard normal variate (SNV) to normalise the spectral data and remove the scatter. Partial least square regression (PLSR) was applied to build the prediction model between DM yield and spectral reflectance data.

Results and discussion

The ultrasonic sensor-based crop height was strongly correlated to the ruler-based crop height, with R^2 of 0.86 (Figure 1). The relative root mean square error (RRMSE) of predicting sward height by ultrasonic sensor was 9%, highlighting the high accuracy of predicting sward height with an ultrasonic sensor. The advantage of an ultrasonic sensor is its low cost, simplicity and it is unaffected by weather conditions. However, the prediction of crop height by ultrasonic sensor is affected by signal deflection, which is caused by leaf inclination angle and movement of plant organs (Fricke *et al.,* 2011).

With estimation of DM yield, partial least square regression suggested quite satisfactory results with RRMSE of 12 and 13% for both calibration and cross-validation (Figure 2). The R^2 values were 0.81 and 0.74 for calibration and cross-validation, respectively. The high accuracy of predicting legume-grass mixture biomass by PLS was reported by Biewer *et al.* (2009), who found that PLS satisfactorily predicts forage biomass over a wide range of legume proportions and sward ages. To our knowledge, the findings of this study constitute the first report that applies hyperspectral reflectance for estimation of forage biomass in northern Sweden. Besides, the spectrometer used in this study is a commercial tractor-mounted sensor that has been used quite extensively in northern Europe. However, in order to apply the spectrometer for biomass estimation, more data from multiple years are needed to further test the method.

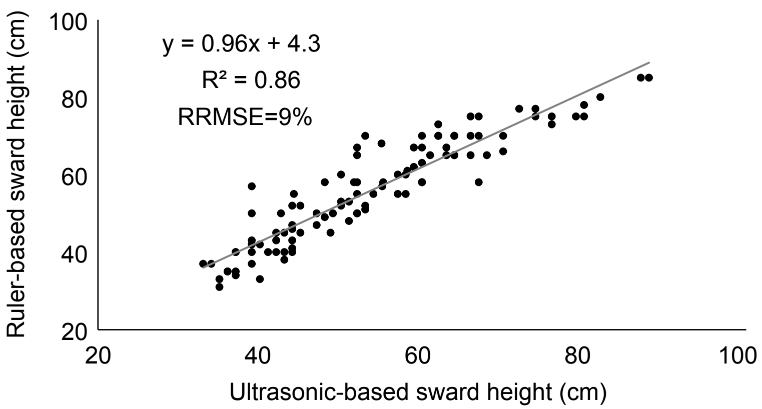

Figure 1. The relationship between sward height measured with ruler and ultrasonic sensor.

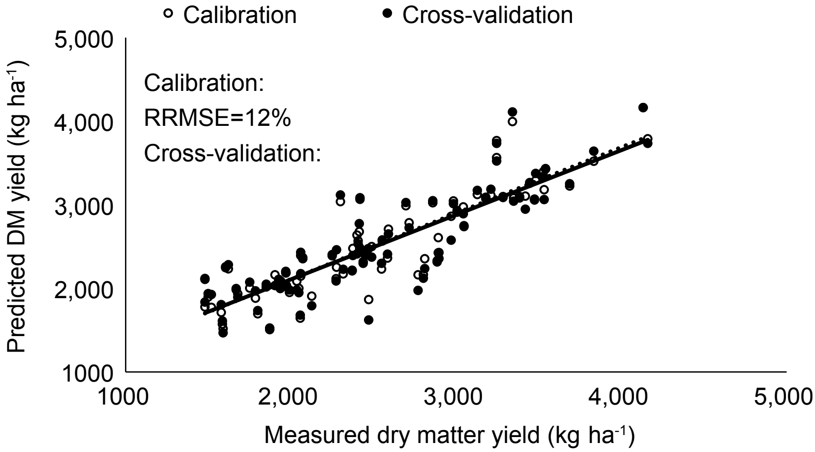

Figure 2. The predicted and measured DM yield by partial least square regression. The optimal number of components selected during the PLSR model process was four. The figure plots both calibration and four - fold cross - validation results. Lines refer to the best fit linear relationship.

Conclusion

The ultrasonic sensor accurately estimated forage height. Its low cost and simplicity makes it applicable to estimate forage height in the field. Dry matter yield of forage was satisfactorily estimated by hyperspectral measurement. With further development, these two non-destructive methods could facilitate farmer decision making, for example, adjusting stocking rates, estimating forage inventory and assessing fertiliser needs.

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Theme 6.
Knowledge transfer to stakeholders

Towards sustainable European grassland farming with Inno4Grass: an infrastructure for innovation and knowledge sharing

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Abstract

European agriculture is facing tremendous challenges related to the rapid decrease of farm populations, competitiveness on open markets and the preservation of natural resources on finite areas. Grasslands, which are highly significant for nature conservation, often face land-use competition with arable cropping, urbanisation and other uses. Farmers need dedicated innovations to improve grasslands economic performance and their effective implementation in practice. This requires co-creation of knowledge between researchers and farmland practitioners, as was broadly pointed out by the European Commission. This paper describes a novel approach to create a collaborative space for grassland innovations contributing to profitability of European grassland farms while preserving environmental benefits. Innovative modes of collaboration between practice and science are enabled by an international thematic network across eight European member states. A methodology serves to collect farmers' innovative ideas and to stimulate collaboration among various stakeholders (farmers' groups, extension services, education and research) including cross-border collaborations, where grassland-related knowledge is made available for local conditions. This interactive innovation model fosters knowledge exchange and establishes a farmland-specific Information Management System. The aim is to stimulate a renewed, collaborative innovation culture for EU grasslands. The methods are conceptualised and put into practice by the Thematic Network project Inno4Grass funded under Horizon 2020.

Keywords: knowledge transfer, knowledge sharing, innovation, collaboration, European Innovation Partnership (EIP), Inno4Grass

Introduction

Grasslands are vitally important both for agriculture and society. Permanent and temporary grasslands cover 61 million ha across the EU-28 representing 16% of the total land area and 40% of the agricultural area in the EU (Eurostat, 2010 in: Osoro, 2014). These grasslands serve multiple functions, including local provision of fodder for animal husbandry (and hence high-quality food provision for citizens), biodiversity conservation, carbon storage and provision of 'traditional' landscapes that European citizens appreciate for recreational purposes and cultural heritage (Silva, 2008; Huyghe *et al.*, 2014; Olsson *et al.,* 2014; Duru *et al.,* 2015; Ryals *et al.*, 2015). The large diversity of management practices, soils and climates enhance the range of ecosystem services provided by grasslands. A large share of European grasslands is exclusively used for animal feed and forms the basis for ruminant production as a significant component of European agriculture. The production of dairy, beef and sheep is of major economic importance to many member states; about 4.5 million farm enterprises held grazing livestock in the EU-28 in 2013

(Eurostat, 2014). The EU farmers often do not perceive the multi-functionality of grasslands as an advantage. This leads to undervaluation and a lack of valorisation strategies. Since market-oriented concepts to create rewards for ecosystem services have not yet been sufficiently developed or understood, their multi-functionality turns grasslands, especially in intensive production systems, increasingly into areas of conflict between food demand and calls for the provision of other ecosystem services.

The numerous economic and environmental benefits of grasslands (e.g. biodiversity, mitigation of climate change) could be further enhanced. This requires innovations in grasslands that provide benefits in both dimensions (Green *et al.,* 2005). Many EU farmers and farmers' associations are struggling to find solutions that would increase the contribution of grasslands in terms of economic added value and at the same time stimulate rural development, ecological and societal benefits such as biodiversity and healthy food production. Furthermore, over the last decades non-grassland-based forms of livestock farming that are based on the intensive use of commercial (and often imported) feed has been less economically viable than many other sectors (e.g. arable production) in many European grassland areas (Huyghe *et al*., 2014). The potential for a better use of grassland for decreasing production costs in livestock farming has also been underestimated. To ensure economic viability for farmers on the one hand and the increasing pressure to reduce the environmental impact of farming on the other hand, farmers and the whole practice communities need innovations.

The aim of this paper is to suggest a collaborative innovation model for grasslands in Europe. First, the political and theoretical frameworks for innovation and knowledge transfer and knowledge sharing are discussed. Then, the EU project Inno4Grass (www.inno4grass.eu) is presented as an example of a conceptual framework that stimulates innovation through collaborative knowledge transfer. Inno4Grass, a thematic network funded under H2020, aims to bridge the gap between practice and science communities to ensure the implementation of innovative systems on productive grasslands and to increase the profitability of European grassland farms and to preserve environmental values.

Framework for innovation

The urgent need for innovations in agriculture has recently been emphasised by the European Commission (EC) (COM 2020, 2010; COM 571 final, 2011; COM 79 final, 2012; OECD, 2017). Meeting the future demand of food from an increasing world population with less impact on natural resources on finite areas for production poses tremendous challenges to the entire agricultural sector. This requires a fundamental rethink of established best practices, in the EU and elsewhere.

The EU's response to these challenges is being developed in the context of an overarching strategic policy orientation towards stimulating economic growth based on innovations, sustainability and smart and inclusive knowledge and learning systems (COM, 2010).

Innovations for grasslands need to consider the connection and potential trade-off between productivity and provision of public goods, in particular, ecosystem services. Moreover, these connections and trade-offs are often context- and place- specific. Local land users and stakeholders often have relevant place-specific knowledge that is essential not only for implementation but can also form the basis of innovations and learning.

Although the need for innovations has been expressed, successful innovations can hardly be imposed. Sustainability-oriented innovation policy needs to create context conditions that stimulate the creation and diffusion of innovations that typically require multi-stakeholder collaboration. An innovation is an idea, practice, or object that is perceived as new by an individual or other social unit of adoption (Rogers, 2003). The subjective novelty generates uncertainty and people will look for more information about the practicability and advantages of the innovation, but also its coherence with social norms and expectations (Rogers, 2003). The OECD (2005) defines innovation as 'the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace or external relations' (OECD, 2005). For Horibe (2007), innovations are more ambitious and should trigger a ground-breaking, category-shattering, revolutionary change in the way people see the world. Hence, those innovations may be rupture innovations in comparison to incremental innovations, where all components of a production system benefit from small progressive steps. One may assume that the latter might be more likely to be adopted by the actors of a social system. However, an accumulation of incremental change can lead to transformative change over time.

While 'innovation' has often become synonymous with 'product innovation', the term includes the introduction of novel services, management processes or organisational practices, and even social innovations (Mulgan, 2006), e.g. micro-finance or community-supported agriculture. For the future development of grasslands, all types of innovations are likely to be essential. Social innovations that connect grassland use and ecosystem services to societal needs will also need to play a role.

Rogers' (2003) work on innovation diffusion has been highly influential in shaping our understanding of innovation processes. Rogers conceives an innovation as a novel idea that has been generated outside a social system and which is then spread and adopted throughout the system through communication (Rogers, 2003). The theory highlights the importance that an innovation is made accessible and that its effects can be observed to allow a judgment about its usefulness. From the farmer's perspective, it seems irrelevant whether an idea or solution is globally new or just new to them. For the farmer it is crucial that the novelty, whether globally new or already existing in another region, will be made accessible for him and works effectively and hence, as innovation for him. Adoption of innovations may be facilitated through different mechanisms that will increase rates of adoption (Arthur, 1994) and tackle path-dependency of established practices. Among those mechanisms, learning by doing or by using and direct network externalities (groups of farmers) have proven very effective (Arthur, 1994).

However, more recent work has emphasised that innovation processes are often not exogenous, but endogenous to social systems. Rather than conceptually separating the source of an innovation and the social system through which it spreads, the dominant line of innovation research has now adopted the concept of an 'innovation system' (e.g. Nelson, 1993). National, regional or industry-specific networks of actors, rules and organisations determine the ability of a society to create and adopt innovations, but their interests, norms and skills also shape the direction of the innovation process. Often one actors' innovation also needs to align with innovations by others, an interdependence that has been characterised as 'innovation ecosystem' (Adner, 2006).

Innovation processes in agricultural systems typically involve a wide range of actors, including researchers, farmers, advisors, agribusiness, retailers, non-profit organisations, etc. These innovation systems also interact strategically with their environment (Klerckx *et al.*, 2010). Nevertheless, innovations are only successful when they have reached a broader acceptance, when they are disseminated and adopted within a social system such as rural communities, peer groups, regional networks, etc. (Ouedraogo and Bertelsen, 1997; Planck and Ziche, 1979). However, despite the more systemic approach to innovation systems, many gaps and deficits remain, for instance:

- Often research is insufficiently linked to practice while scientific novelties innovations stimulate limited practical innovations.
- Many farmers are not well integrated into innovation systems, so that their needs are not sufficiently considered during innovation generation.

- Innovative ideas from practitioners are not easily captured and up-scaled, i.e. local or practice-generated innovations with strong potential for dissemination are often not recognised (EU SCAR, 2013; World Bank, 2006).

Many innovation theories conceptualise collaboration and communication as a relationship between a source (or sender) and a receiver. Putting only such an asymmetrical relationship at the centre is problematic. The assumption of two distinct types of actors where the source or sender shares the knowledge and the receiver acquires the knowledge suppresses any vision of collaboration where every partner has something to contribute. Moreover, innovation in this context of 'co-creation' is a complex process with various prerequisites, factors and contextual issues. Therefore, we see the term 'knowledge-sharing' as more adequate than the term 'knowledge transfer' in the context of innovation and this has become a broad research topic in social science.

Several reasons explain the low rate of innovations in grasslands:

- Grassland-based production systems are complex and diverse; therefore, innovative systems must be implemented as a combination of innovative practices with place-specific adaptations that are strongly dependent on local conditions, often amounting to 're-invention' (Rogers, 2003); the novel practice finally implemented is then a co-product of scientific and practitioner innovation.
- Benefits from innovation in grasslands are often perceived only after considerable time-lags.
- Grassland innovations affect various aspects of sustainability (profitability, environment, social acceptance) and often in contradictory ways.
- Limited interaction between farmers and research hampers context specific re-invention.
- Grassland-related innovation systems are underdeveloped in comparison to those related to arable-land or animal production systems.

These observations have challenged established knowledge transfer methods and structures and triggered calls for a socially attuned approach that considers interrelations, trust, power, social capital and networking. One line of thought has emphasised the co-creation of knowledge between scientists and different groups of practitioners and the role of knowledge brokers (Klerkx *et al.,* 2009). This approach sheds new light on the processes of knowledge transfer. However, there is no blueprint for successful innovation processes and the influencing factors are manifold and situation-specific (Rogers, 2003).

In the following section the most relevant aspects of knowledge transfer and knowledge sharing for innovations and innovation management in grasslands are compiled and explained. The move from knowledge transfer to knowledge sharing corresponds to the shift from innovation dissemination models to innovation system thinking. Based on these conceptual considerations, we then explain the methodology that has been drawn up for the Inno4Grass project, a thematic network funded under H2020 which started in January 2017.

Framework for knowledge transfer and sharing

Knowledge transfer (KT) is the area of knowledge management that is concerned with the exchange of knowledge across the boundaries of specialised knowledge domains (Carlile and Rebentisch, 2003). Knowledge Transfer is the conveyance of knowledge from one place, person, venue or organisation to another. In the traditional sender-receiver model, KT is successful if the receiving unit accumulates or assimilates subjectively new knowledge. In this respect, KT involves either communication efforts to disseminate knowledge, or active attempts to approach others in order to learn what they know (van den Hooff and de Ridder, 2004).

Knowledge types in agricultural practice

Four types of knowledge that advisors and hence, farmers need to master can be distinguished:
- know-what;
- know-why;
- know-how; and
- know-who.

These knowledge forms can be clustered into two complementary main types: codified or explicit knowledge (know-what and know-why) and tacit knowledge (know-how and know-who) (Klerkx and Proctor, 2013, Ingram and Morris, 2007, Lundvall and Johnson's, 1994).

Explicit knowledge (know-what and know-why) is standardised knowledge that can be systematised, presented in writing, stored and transferred. It is at the core of the scientific and technical publication systems, as exemplified in patents. Often explicit knowledge is also referred to as information.
- *Know-what* refers to knowledge about facts, including observations, classifications, measurement and cataloguing of natural phenomena.
- *Know-why* is knowledge of principles and causal models, often embedded in science and technology.

Tacit knowledge (know-how and know-who) is implicit, local, context dependent and inherently intangible. It results from talent, experience and abilities.
- *Know-how* refers to skills, the capability to do something at practical level as reflected in action, applied to specific cases or settings.
- *Know-who* refers to the social capital of a person, which includes his or her networks, access and norms of reciprocity.

Models to describe knowledge transfer

The process of KT has been widely studied in social sciences.

Major and Cordey-Hayes (2000) distinguish node and process models of KT:
- Node models describe nodes and identify sequences of steps necessary for a knowledge transfer process.
- Process models describe knowledge transfer as separate processes that are each undertaken.

In node models, actors and networks are presented as nodes with links (ties) between them depicted by connectors (lines). Actors are categorised as committed or influential (ODA, 1995) and ties between actors can be strong or weak. Both strong and weak relationships (i.e. ties) are important for the diffusion of new ideas (Newell *et al.,* 2000). Strong ties are close associations among firms, whilst weak ties link individuals from organisations across different sectors or communities that would not normally make contact during their day-to-day business. These can be equal or more important in the diffusion process because, through weak ties, organisations can encounter ideas that go beyond their usual ways of operating. In process models, the knowledge transfer is described as separate processes that are each undertaken.

'Linear' knowledge transfer models are sometimes linked to the slogan 'getting research into practice', assuming that there is a provider or source of knowledge (e.g. a scientist) and a receiver (typically a farmer) who subjectively acquires new knowledge. In a linear pathway, from generating research evidence to evidence-informed farming practice, know-how is transferred in a linear and directed way through a series of predetermined steps. This approach is supported by empirical evidence showing that clear, relevant and reliable research findings facilitate the use of evidence-based farming practice. Integrated K models rest

on the assumption that technical and organisational innovations result from a back-and-forth process between different fields of knowledge, namely:
- scientific knowledge; and
- knowledge from practice.

Integrated KT models extend the linear models where complexity of domain(s) is high. They are especially relevant where 'one size fits-all' solutions (e.g. due to high dependency of success on variable local conditions) are not possible, like in the case of grasslands. Grasslands exhibit a diversity of conditions which require development of locally relevant strategies to deliver the best economic, environmental and societal benefits from grasslands.

Agro-ecology illustrates a particular relationship between knowledge production and practice, the two processes being no longer distinct and successive but, on the contrary, closely linked and complementary. The production of new knowledge is then akin to 'integrated sequences of description, research and action' (Chevassus-au-Louis, 2006). It is then necessary to move from a linear and implicitly top-down and centralised knowledge production model to a more bottom-up approach (Reed *et al.*, 2006) or horizontal approach (Peeters, 2015), or to encourage the consideration of local diversity rather than an orientation towards generalisation and centralised standardisation (Chambers, 1994). Moreover, agro-ecology offers a new insight regarding dependency of success on local conditions. The usable knowledge is generated through co-production by researchers and practitioners.

The Agricultural Productivity and Sustainability European Innovation Partnership (EIP-AGRI)

The Innovation Union initiative (European Union, 2013), an action-packed initiative for an innovation-friendly Europe emphasises that research and innovation are key drivers of competitiveness, jobs, sustainable growth, human health and social progress. The concepts for innovation partnerships in agriculture were established in a Foresight report by the EU's Standing Committee for Agricultural Research (EU SCAR, 2013). The report, merging linear and integrated KT-models, highlighted the need for a fundamental reorientation of the knowledge transfer approach in agriculture, in particular of the organisation of rural extension and training. From a policy perspective, skills and knowledge of land managers in supporting more sustainable land use and food production have become a key focus of both government and industry (Klerkx and Proctor, 2013). Following this line, the European Commission (EC) launched the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI) in 2012 to contribute to the European Union's strategy 'Europe 2020' for smart, sustainable and inclusive growth.

With the implementation of the EIP-AGRI, new paradigms were assumed to redesign traditional KT models between science and practice. The EIP initiative aims to address deficits in innovation provision for farmers which result from insufficient information flows between practice and science. To achieve this, the EIP-AGRI aims to:
- Provide a working interface between research and farming practice and encourage the wider use of available innovation measures.
- Promote faster and wider adaption of innovative solutions in practice.
- Inform the scientific community about the research needs of farming practice.

The EC established EIP-AGRI Networks to facilitate communication and exchange on innovation-related information, research results, practice needs, and lessons learned. At both national and regional levels, operational groups funded by the second pillar schemes of the CAP, aim at practical implementation and experimentation.

Since 2014, funding has been provided for projects that facilitate knowledge exchange and collaboration between farmers, researchers, advisers and agri-business to tackle the prevalent needs from the field, supporting the idea that innovation is strengthened by combining knowledge and experiences from a diverse range of people. The concept for multi-actor projects and thematic networks has been laid down in the EU research programme Horizon 2020 (COM, 2017). Support for innovation brokers and innovation centres is also envisaged under the EU Research and Innovation Framework Programme and Cohesion and Education Policies.

In its communication paper about the future of food and farmers, the European Commission has stressed the importance of knowledge transfer and innovation for the next CAP and suggested that 'the strengthening of farm advisory services should become a condition for the approval of CAP Strategic Plans' (COM, 2017).

Currently, 17 network projects are funded under this programme. One of these is Inno4Grass. It is presented here as an example of a proposal to actively encourage innovations in the thematic area of grasslands.

Concept and approach

The objective of the Inno4Grass project is to develop and implement a methodology for an efficient and effective framework for: (1) collecting innovations in grassland management and grassland-related production from commercial farms and from literature and (2) boosting adoption and diffusion of innovations. This is achieved through extending traditional knowledge transfer approaches and enabling the co-creation of new knowledge and knowledge sharing by a coordinated set of integrated networking activities.

The overall concept of the thematic network project Inno4Grass draws on the identification and promotion of innovative practices and systems for sustainable grasslands. It is based on innovative interactions in a multi-actor approach linking farming practices with science. It is considered that the diversity of conditions likely requires locally relevant strategies to deliver the best economic, environmental and societal benefits from grasslands. A mix of stakeholders such as farmers, researchers, advisors and teachers are actively involved in the project.

Inno4Grass uses a combination of traditional skills and new ideas allied to technical know-how and promotion through:

- Identifying innovative grassland farmers as leading examples and capturing innovative ideas from practice via networks and internet.
- Promoting adoption through farmers' groups and early adopters by establishing a multi-stakeholder collaboration and learning network.
- Active dissemination, i.e. by stimulating activity of grassland networks with facilitator agents, to persistently bring together and sustainably deploy know-how and innovations.

It is also assumed that essential innovations on grasslands and their use may be located at other layers of the whole production chain. Therefore, the analysis of the farming systems includes milk and meat processing, production, processing and marketing.

The overall conceptual approach makes it possible to better exploit the latest achievements in applied research or even at preliminary stages of testing, and at the same time, to create more attentive audiences for innovative practices implemented by the most advanced farmers.

Because of the high dependency of grasslands on variable local conditions, many innovations in grasslands originate from farmers' practical experimentation as they exploit the diversity of conditions, so farmers can learn from other farmers. But it is also possible to learn across local experiences, to understand and systematise factors of success and to consolidate good practice through scientific causal understanding and generic knowledge. Moreover, this dual approach, which is adopted in Inno4Grass, improves the pace of both novelty creation and adoption across localities; both aspects being in the very core of innovation (OECD, 2005).

Inno4Grass aims to benefit from the diversity within the farmers population, as identified by Rogers (2003). The project captures innovations from farmers who belong to the 'innovators' group and facilitates dissemination to farmers groups organised around farmers belonging to the 'early adopters' group (Figure 1).

The Inno4Grass consortium has identified 'innovators' and 'early adopters' among grassland farmers across the participating countries. Identification was based on the knowledge of networks of consortium partners that have close links to practice communities such as Chambers of Agriculture or extension service organisations. A guideline has been created to describe and suggest appropriate criteria and methodologies for the selection process.

The consortium considers the early adopters group to be farmers with substantial know-what, know-how, know-who and the ability to adopt innovations in the context of EIP-Agri. Once adopted or adapted, innovations will be further communicated to the other groups through various means of dissemination and training methods, such as an Information Management Systems (IMS) including websites, videos, brochures, etc., in close collaboration with the media. As a result, the network contributes to innovations in grassland-based farming systems by closing the gap between farmers and researchers and between practice and science. This will be achieved through a wide range of innovative interactions and tools and by developing additional resources. Three components can be distinguished:

1. Adopting scalable approaches to enable the tapping of innovative capital of outstanding practices and systems from the most innovative farmers.
2. Implementing appropriate methodologies for multi-actor collaboration between practice and science.
3. Implementing validated methods and tools to synthesise, disseminate and exploit knowledge.

Adopting scalable approaches to enable the tapping of innovative capital

In Inno4Grass, a direct approach of involving innovative farmers is implemented through interviews, consolidated through case studies and further debated through electronic discussion groups. The inclusion

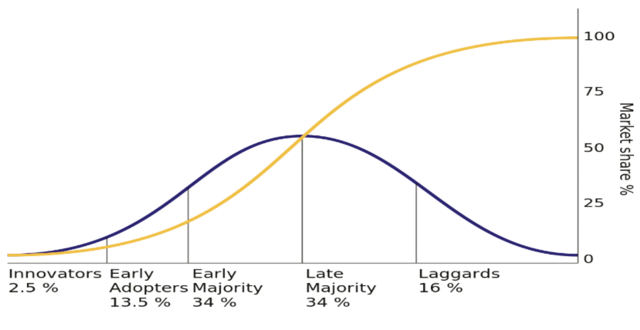

Figure 1. Adapted from Rogers (2003); showing the frequency and cumulated frequency of actors regarding their attitude towards production and adoption of innovations.

of farmers in the design and roll-out of innovations will contribute to closing the gap between practice and science. So far, an inventory of 170 innovative farmers has been created, which is equivalent to 170 innovations or innovative systems. From this group of farmers, potential grassland innovations were gathered through face-to-face interviews, conducted during site visits of about half a day. The information was collected by a standardised questionnaire on structural parameters and by open questions on the general functioning and innovations of the farm.

Inno4Grass has developed innovative methods for detecting innovations during face-to-face meetings and surveys. Guidelines and standardised questionnaires to identify and describe these innovations with meta-information have been set up. These potential innovations adapted to different farm types were identified, inventoried and stored in a database. In addition to these interviews, an email questionnaire was sent to members of Farmer's Unions and Livestock Breeder associations in the eight partner countries, asking them *inter alia* to identify innovative practices and farmers.

The internet provides an excellent forum for open discussion since individuals tend to be more open in web-based settings where they are not being physically judged or scrutinised and feel more comfortable sharing (De Vun, 2009). The dispersed knowledge collected from individuals is expected to generate a heterogeneously growing know-how resource. After structuring, this knowledge capital will be shared with other stakeholders in linguistic groups and groups from other countries, using specifically created electronic discussion groups.

Implementing appropriate methodologies for multi-actor collaboration

Inno4Grass facilitates collaboration between various actors from science and practice (farmers, farmer's organisations, advisors, researchers, etc.). Project partners conduct multi-actor meetings and interactions on farm-level grassland issues that address innovation needs and avenues for tackling these needs. The multi-actor events build on innovations tapped from farmers' knowledge from science (Caron *et al.*, 2014) and experiences and expectations of stakeholders all along the supply chain. This combination is expected to create an improved innovation flow. An inventory and evaluation of existing structures fostering innovation management and brokering and their practices will enable the creation of a European innovation space for grassland-based farming, extending and connecting existing structures. A common learning environment on grassland-based farming systems will improve the scope for anchoring new grassland developments.

Inno4Grass will develop and test a new method for quantifying the success of a grassland management system with relevant indicators that can be easily collected on farm. The project will develop a facilitation method for stimulating the participation of farmers in workshops where different categories of stakeholders, including scientists, meet. Inno4Grass will also initiate the use of Wikimedia platforms in a farming environment as a tool for the interactive exchange of information, an approach that has proved efficient in many farming communities (Adamides and Stylianou, 2013).

A focus of the Inno4Grass project is to embed farmers' know-how on grassland-based production systems with research and development results in a participatory approach. Grassland knowledge and innovation are useful if readily available to the end user. A combination of integrating current explicit knowledge of both farmers and researchers with new knowledge by active interaction between farmers and researchers is used to create a flow of innovation with respect to grasslands and grassland-based farming and production systems in Europe. Ensuring that best practices in grassland management will be rewarded by grassland peers is a new concept of promoting excellence in practice. Inno4Grass aims to introduce the rewarding of excellence in grassland management. This is important as it sets out a distinct standard for grassland stakeholders to adopt and adjust to. Inno4Grass will challenge the European grassland community to improve, innovate and set a clear agenda for improvements in managing the key resource grasslands and to set a new research agenda for sustainable productive grasslands.

This ambitious approach has been made possible by the composition of the consortium, which includes groups from farmers' organisations, extension services, applied and basic research and education. In order to strengthen the project, a team of facilitator agents is being established. This concept has already been successfully implemented in the Winetwork (http://www.winetwork.eu/facilitator-agent.aspx). The team of facilitator agents builds on two persons from each of the eight participating countries and will lead the discussion groups and forum, the meetings between farmers and science and most field days. They will be trained to further increase their competencies in technical and scientific knowledge regarding grasslands but also in the skills to run groups gathering a broad range of stakeholders (Guo and Iyer, 2010). This unique human resource will stay active after the end of the project. It will not only be a backbone for this thematic network but also for the grassland community across Europe.

Implementing validated methods and tools to synthesise, disseminate and exploit knowledge

Inno4Grass will combine traditional survey and monitoring methods with electronic communication methods. Inno4Grass aims at facilitating grassland management decision-making by developing a coherent ICT infrastructure for knowledge sharing and innovation (Nakasone *et al.*, 2014). That will help farmers to take the best possible decisions, test their ideas and take advantage of the experience of their colleagues in the daily management of their farms. The project will identify the best grassland management software for each country and will support the generalisation of their use in farms. This will improve the precision of grassland management practices and improve the efficiency of home forage resource use.

Participatory approaches will be put at the disposal to contribute to faster and more realistic development and implementation of innovations. The practical and previously tacit knowledge of farmers and advisors will be combined with the more theoretical and explicit knowledge of scientists that has been validated in an established peer-to-peer process. The innovations produced (which will be summarised in practice abstracts) will be made available for large groups of practitioners across a diversity of local conditions.

Within Inno4Grass, intermediating actors and farmers groups (often combined in EIP-Operational Groups) will play a key role in supporting the adoption of novel technologies.

This is important for grassland farmers because: (1) the dependency on local conditions for forage production and use of feed in animal production systems is stronger than in most other agricultural sectors; and (2) the multiple channels can be used for disseminating information and knowledge relevant to grasslands (via practice abstracts, newspapers, social media but also via advisors, seed merchants, technicians for animal production, etc.). When learning from other regions or member states it should always be considered that a 'one-size-fits-all' solution does not exist. In Inno4Grass, learning is facilitated by the interaction of case study farms, practical and scientific knowledge and by broad dissemination, both through electronic resources and field events. Inno4Grass will initiate a dynamic European exchange platform in Operational Groups (connected to EIP-AGRI) that will persist after the end of the project and will make the European grassland farming community more linked and interactive for the future.

Conclusion

Dedicated innovations for the improvement of grassland performance and their effective implementation in practice are urgently needed to maintain the viability of grassland-based farming across Europe. Interactive innovation models fostering knowledge exchange between practice and science have proven to facilitate such innovations. Usable knowledge is more likely created jointly by researchers and practitioners; an understanding of what works and why is gained through an interactive construction and sharing of knowledge that involved researchers and practitioners to combine generalised and previously tacit knowledge. The creation and diffusion of innovations in agriculture is therefore best understood as a social process that involves iterative knowledge exchange and interaction. Moreover, the diffusion of innovation for grassland in linear models is limited due to the high dependency on local conditions. The theoretical framework of the approach is that the Inno4Grass thematic network will facilitate the identification and testing of innovative ideas from grassroots, facilitate consolidation with scientific knowledge and enrich the research agenda. Inno4Grass provides an example of an approach to create a space for innovation on grasslands that aims at increasing profitability of European grassland farms and at preserving environmental values through innovative collaboration modes between science and practitioners set by an international network across eight European member states. Methodologies to obtain extensive collections of farmer's innovative ideas, collaborative works among different stakeholders (farmers groups, extension services, education and research) and cross-border collaboration where grasslands-related knowledge is made available and adapted to local conditions have been designed. This interactive innovation model that fosters knowledge exchange and implements an Information Management System is expected to stimulate a new innovation culture for EU grasslands.

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Suitable cows for grass-based systems: what do stakeholders do in France?

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Abstract

Breeding suitable dairy cows for a grass-based system is an emerging concern in France to improve farm sustainability. The lack of genetic tools to support farmers in the genetic management of their herd grazing abilities could represent a potential lock-in for the improvement of grass use on farm. This study is based on French dairy-cattle farmers, breeding societies and inseminator viewpoints and practices regarding cow adaptation to grass-based systems. Three technical tools are highlighted as '*locks-in*' to the breeding of adapted dairy cattle to grazing conditions: the ISU (global merit index), the mating plan and milk performance indicators produced by milk recording. Crossbreeding practices are identified as a strategy to step-out the locked systems and quickly improve grazing capacities of cows. These results underline the need for a participative reflection on the breed selection scheme organisation.

Keywords: dairy cow, grazing system, genetic selection, socio-technical transition

Introduction

In a context of climate and price variability, a better use of local forage resources, particularly grass is a lever for dairy cattle farmers to reduce their dependency on inputs while improving farm sustainability. Such a strategy requires farmers to breed suitable cows for grass-based systems capable of efficiently transforming forages into milk and improving reproductive efficiency while facing feed resource variability (Delaby *et al.,* 2009). In France, breed genetic orientations do not explicitly refer to these performance traits and a lack of tools to support farmers to select cows which are adapted to grass-based systems was reported (Tixier-Boichard *et al.,* 2015). In such a context, the questions are: how do dairy farmers breed suitable cows for grass-based systems? And how do actors involved in dairy cow genetic selection support them effectively to such ends? This paper aims to identify the main locks-in, considered here as widely used and diffused technology or practice detrimental to transition and innovation, to the breeding of suitable dairy cows for grazing by analysing the technical tools designed and used by the main French breeding system actors. This paper also explores if farmers adopted adaptation strategies to step-out of system locks-ins (Geels, 2004): get out of the main regime by innovating and adapting the technology and practice to their own context or objectives.

Materials and methods

Our study is based on qualitative data collected in several studies carried out in different areas within France (Auvergne, Midi-Pyrénées, Brittany, Normandy, Rhône-Alpes) between 2014 and 2016. Interviews with 70 dairy farmers were conducted (47 with pure breed herds, 23 who crossbred) regarding different aspects of the breeding process: cow characteristics and breeding practices associated with robustness (Ollion, 2015); the characterisation of the transition process from purebred to crossbred herds (Basset *et al.,* 2016) and the relationships with inseminators (Daubard *et al.,* 2017). Representative from six dairy cattle breeding societies were interviewed to understand the consideration of adaptation capacity traits in the breed selection schemes (Cloet *et al.,* 2015). Three inseminators were interviewed to understand their job evolution (Daubard *et al.,* 2017). Data were analysed using the actor network theory (Callon,

1984) focusing on the role of technical tools in order to understand actors' interactions and knowledge articulation (Labatut *et al.,* 2009).

Results and discussion

The use of three main technical tools was identified as locks-in to the breeding of dairy cows suitable for grass-based systems. First, the global merit index (ISU) is, for most farmers, the main indicator to select a sire for insemination, despite a lack of understanding of its origin and meaning. In practice, some farmers select bulls with the highest ISU score without looking at its composition and others completely delegate the choice of bulls to inseminators. Such a use of ISU prevents farmers from selecting bulls on specific characteristics regarding their farm context or objectives and requires them to rely on the breed orientations. Conversely, for all breeding societies, the ISU can allow dairy cows adapted to grazing conditions to be selected by virtue of the increased relative emphasis on functional traits (fertility, legs, udder health, etc.) within the index. For local breed representatives (Abondance, Brown Swiss), grazing abilities are inherent to the origin and history of the breed: 'the breed was made by the mountain'.

The second breeding tool is the mating plan, i.e. choosing the bulls to reproduce with each individual cow. Some farmers choose a small number of bulls based on two or three important indexes to mate with all the females of their herd, independently from their individual characteristics. The majority of these farmers completely or partially delegated the mating plans to their cooperative inseminators or breeding societies' advisors because of the large number of bulls available and their rapid turnover. Interviewed inseminators mostly developed mating plans based on the main breeding objective of the breed(s) used, when farmers are not involved in the decision.

The third breeding tool is milk performance indicators produced by milk recording organisations, to which the majority of the interviewed farmers are members. An annual milk recording summary is sent to each farmer (containing indicators on milk volume, composition, reproductive performance). All farmers considered such indicators as useful tools for their herd management notably for breeding practices. Nevertheless, farmers looking for cows adapted to local grazing conditions explained that individual performance should be assessed only over the long run, notably over several reproduction cycles.

To step-out these previously identified locks-ins in pure breed selection schemes, 15 farmers started implementing strategic and long term crossbreeding (Figure 1). They aimed to achieve rapid progress regarding several characteristics considered as essential for the balance between cow and grass use:

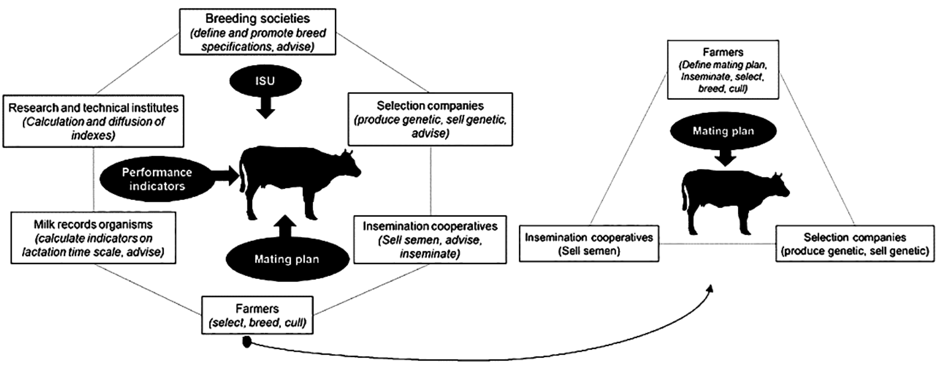

Figure 1. Representation of the strategy implemented by farmers to step-out from the locked sociotechnical systems of dairy cow genetic (left) to the unlocked system (right) through crossbreeding of dairy cow. Actors of the system are represented in the white boxes and technical tools in the black circles.

fertility, health and grazing behaviour. This system transition can be implemented in complete disruption to the main system, with farmers withdrawing from cooperative or advisory services and giving up on the main technical tools (ISU, milk records). These farmers re-appropriate genetic management on farms, building their own mating plan and even their own selection indexes. Some farmers still rely on breeding societies and selection companies, buying French bull semen, but some also started importing semen from other countries (Ireland, New Zealand) to get more adapted genetics for their grazing systems.

Conclusion

Currently, three main paths are evocated by different actors to improve the grazing capability of dairy cows: (1) allowing more weight to existing functional traits in the ISU; (2) using local breeds relying on their natural ability to adapt to local grazing systems; and (3) experimenting with a new breeding system using crossbreeding leading to the re-appropriation of on-farm genetic management by farmers. The transition from the main genetic regime to crossbreeding indicates that a better support system is needed to transition toward grass based systems. This support should lead to the development of technical tools helping the on-farm management of genetic selection considering specificities of the local context and of farmers' objectives. Participative reflection including all actors of the dairy cow genetic selection process should be implemented in order to redefine collectively selection scheme organisation to reconsider technical tools. Our results also suggest that within-breed reflection could lead to the exclusion of farmers who are crossbreeding.

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Evaluation of horse farmers' knowledge and attitude towards grassland management

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Keywords: horses, grassland management, education

Introduction

Horses are playing an increasing role in managed grasslands. About 3.5 million hectares of grassland are managed for approximately six million horses in Europe (Jouven *et al.*, 2015). However, systematic research on grassland management of horse farms is sparse. In particular, horse farmers' grassland specific education and attitude towards grassland management have not been investigated so far. A better insight into this issue is required to improve extension services for horse farmers.

Materials and methods

An online-survey based study was conducted in 2017 in Germany. Data on 700 horse farms were collected. Requested information included farm structure (professional, semi-professional, pleasure) and farmers education (education in agriculture, in horse husbandry, no such education). Attitudes towards grassland management were determined using Likert-scale questions.

Results and discussion

The majority of participants (70%) keep horses and manage grassland for pleasure. These farmers have no strong economic incentives to intensify their grassland management. Less than 30% of the participants have a professional background or education in agriculture (19%) or horse husbandry (25%). However, improved grassland management is stated to be important for several reasons including: forage production (75%), nature conservation (62%) and to provide a good appearance to support a good overall farm image (58%).

Eighty percent of professional farmers consider grazing as an important topic mainly because grazing of horses is usually requested by their customers. Horse owners demand regular grazing, for the reasons of animal welfare (97%), provision of environmental stimuli (93%), facilitation of social interactions among horses (94%) and locomotion (97%).

Knowledge transfer is specifically requested by horse farmers. More than 90% of participants would like to improve their knowledge on sustainable grassland management and more than 80% believe that horse farmers should receive better and more specific education on grassland management. As the main specific issues of interest related to grasslands managed for horses, the respondents specified fructan content of grasses (80%), reseeding of pastures (80%) and biodiversity and nature conservation (75%).

Conclusion

There is a remarkable variability in horse farmers' education, knowledge and attitude towards grassland management. We consider that horse farmers should generally receive better and more specific education or advice on grassland management to enable more sustainable grassland management in the equine sector.

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A case study on the adoption of grazing skills and technologies on the Teagasc BETTER sheep farms

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Abstract

The Teagasc BETTER (Business Environment and Technology through Training Extension and Research) sheep farm programme was designed to establish focal points for the on-farm implementation, development and evaluation of technologies relevant to the sheep sector. Each farm has a detailed farm plan designed to improve the productivity and profitability of the flock over three to five years using the latest technologies and research findings. A key message coming from the Teagasc sheep research programme and the BETTER Sheep Farms is the importance of grass production in improving farm profit margins and sustainability. Each of the BETTER sheep farms follows three key principles to improve grassland management: (1) address soil fertility issues based on soil test results; (2) improve grazing infrastructure using permanent and temporary grazing divisions; and (3) measure grass growth weekly and use the data to make and implement grassland management decisions. On one of the farms where these three principals were adopted, a 19.0% increase in grass production was recorded over a four year period between 2012 and 2016. This increase in grass production reduced concentrate feed costs by 10% per ewe while supporting an increase in flock size with stocking rate increasing from 2.29 to 2.46 LU ha^{-1} during the same period.

Keywords: BETTER Farm, sheep; soil fertility; infrastructure; grass measuring

Introduction

The Teagasc BETTER (Business Environment and Technology through Training Extension and Research) sheep farm programme was designed to establish focal points for the on-farm implementation, development and evaluation of technologies relevant to the sheep sector. Recently, reports by Campion *et al*. (2017) and Earle *et al*. (2017b) have shown the potential performance achievable from grazed grass in a mid-season lambing production system. The adoption of technologies to improve grassland management practices on sheep farms has been to the fore in the BETTER sheep farm programme. This paper quantifies the effect of adopting grassland technologies on the physical and financial farm performance of one of the Teagasc BETTER sheep farms.

Materials and methods

Upon commencement within the program, a detailed farm plan was drawn up for all farms focusing on flock breeding, flock size, flock health, flock structure and grassland management. Within the grassland management plan designed for the farms, the three key areas primarily focused on were soil fertility, grazing infrastructure and grazing management. Soil samples were taken across the farm in February 2012 (commencement of BETTER farm programme on the farm) and on one third of the farm yearly in February 2015, 2016 and 2017. Samples were taken using a soil core to a depth of 10 cm and submitted to a commercial laboratory for analysis. The results were used to inform decisions on lime and fertiliser requirements. Regular grass measuring was carried out on the farm using a rising plate meter throughout the grazing season with the measurement data used to inform grazing plans on the farm and measure grass production. Grass production data from 2014 to 2016 were considered when analysing changes in grass production on the farm as they were recorded using the Teagasc PastureBase system (Hanrahan *et al*., 2016). This grazing data was used as part of the grassland management decisions on the farm including grazing infrastructure and in particular, the use of temporary grazing divisions where necessary. Grazing divisions were adjusted continually based on grazing group size and grass demand. Performance of the sheep flock on the farm was recorded using EID technology and analysed through SAS 9.4. Financial performance was measured using the Teagasc E-profit monitor system and figures reported are for gross margin ha^{-1} (margin remaining following removal of variable costs e.g. feed and fertiliser).

Results and discussion

The percentage of soil samples showing below optimum pH and P decreased from 2012 to 2017 as a result of a targeted fertiliser plan. In the same period, the percentage of paddocks which were at optimum levels for all key variables (pH, P and K) increased from 17% to 33%. Grass production data from 2014 and 2016 indicate a 19% increase in this period. Stocking rate also increased from 1.7 to 2.46 LU ha^{-1} during the same period, 2.46 LU ha^{-1} being the equivalent of 12.3 ewes ha^{-1}. In comparison with the average stocking rate on Irish sheep farms, which was reported to be 5.97 ewes ha^{-1} (Bohan *et al*., 2017), the increased focus on soil fertility and increased grass production stocking rate was almost twice this on this particular farm. Between 2014 and 2016 there was a 10% reduction in concentrate feed costs per ewe. Concentrate feed accounted for the highest proportion of variable costs on sheep farms and any reduction in the amounts used is considered highly desirable. The performance of the lambs bred from mature ewes in the flock in 2017 is presented in Table 1. Lambs were reared to weaning without concentrate supplementation being offered to them or their dam's post-partum. Target pre-grazing sward heights during the same period was 7 to 10 cm with a post-grazing residual sward height of 3.5 to 4 cm. The weaning rate for the flock was 1.54 lambs per ewe joined making it similar to the medium prolificacy, medium stocking rate system reported in Earle *et al.* (2017a). The latter reported weaning weights of 31.5 kg for both medium prolificacy and medium stocking rate groups, in line with the 31.9 kg average recorded on this farm. The results from this farm clearly demonstrate the potential to replicate the performance reported within the scientific literature for mid-season lamb production systems. When the change in profitability is examined from commencement of the programme on the farm in 2012 to 2016, the changes in soil fertility and grassland management helped support an increase in farm gross margin from €550 ha^{-1} in 2012 to €946 ha^{-1} in 2016.

Conclusion

Table 1. Lamb performance from ewes born to mature ewes in 2017 from the case study Teagasc BETTER sheep farm.

Variable	Birth type			
	Single	Twin	Triplet	S.E.M
Birth (kg)	5.6	4.6	3.9	0.06
49 days post-partum (kg)	23.5	19.9	18.9	0.13
98 days post-partum (kg)	34.3	31.0	29.7	0.31

The implementation of a targeted fertiliser plan based on soil fertility analysis increased the grass output on this sheep farm. The combination of changes in grazing infrastructure, the use of grass growth measurements and key grazing technologies provided information for grassland management decisions resulting in an increased gross margin per ha.

Acknowledgements

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Eurodairy: a bottom-up approach to transfer innovations on grass to European farmers

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Abstract

EuroDairy is a Horizon 2020 thematic network to connect dairy farmers aiming to improve the performance of their farms. The project follows the interactive model of practice-based innovation. It promotes the formation of a cross border network of 42 operational groups and of 120 innovating pilot farmers in 14 different European countries. EuroDairy facilitates intensive interactions so that innovations identified in one country or region can be shared with others. The project focuses on four key topics affecting future sustainability of EU dairy farming: socioeconomic-resilience, resource efficiency, animal care and biodiversity. In many farms or groups, grazing is one of the means chosen by farmers and researchers to improve one or more of these key issues. The aim of our paper is to describe one of these innovations and how it is transferred from farmer to farmer via the bottom-up approach. The topic chosen is to improve understanding of grass growth and quality in various backgrounds, to improve grazing management in Northern Ireland thanks to the 'GrassCheck' innovative programme.

Keywords: innovation, grass growth, grazing, dairy cows, bottom up approach, farm networks

Presentation of EuroDairy project

The EuroDairy project follows the interactive model set out by the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI), putting farmers at the centre of practice-based innovation, adapting and developing new and existing scientific knowledge to produce implementable solutions, which can then be shared across the network (EIP-Agri, 2016). Groups of farmers coming together in the regions (as 'Operational groups') are linked, so that good ideas can be captured and exchanged. Pilot Farmers operating excellent levels of physical and financial performance, demonstrate best practice and push boundaries in the application of new knowledge. EuroDairy facilitates intensive interactions, so that innovations identified in one country or region can be shared with others, via a range of media and easily accessible end-user materials (Keatinge and Korevaar, 2017). The project focuses on four key topics affecting future sustainability of EU dairy farming: socioeconomic-resilience, resource efficiency, animal care and biodiversity.

In many farms or groups, grazing is one of the means chosen by farmers and researchers to improve one or more of these key issues. The topics covered are for instance (Table 1): protein self-sufficiency thanks to grazing, better understanding of grass growth and quality in various backgrounds, renovation and better use of wet grasslands, towards new forage value indicators or a web based forage platform for knowledge exchange between farmers, contractors and advisers.

In this paper we focus on innovations in prediction of grass and roughage production in Northern Ireland through the GrassCheck innovative programme (http://www.agrisearch.org/grasscheck).

Table 1. Innovations related to better use of grazing in EuroDairy pilot farms and operational groups.

Region / country	Topic	Support[1]
France, Brittany	Self- sufficiency in proteins via grazing	PF
UK, Northern Ireland	Better understanding of grass growth and quality	PF
Poland	Grassland renovation and improvement of grazing in wet lands	PF
Germany, Schleswig-Holstein	Use of domestic proteins	PF / OG
Germany, Schleswig-Holstein	Prediction of grass growth	PF / OG
Germany, Schleswig-Holstein	Optimised nutrient management of grasslands	PF / OG
The Netherlands	Grass growth prediction	PF / OG
The Netherlands	New forage value indicator (silage)	PF / OG
The Netherlands	Web forage platform	PF / OG

[1] PF = Pilot Farms; OG = Operational groups.

An innovative solution to improve prediction of grass and roughage production in Northern Ireland (GrassCheck)

GrassCheck is an initiative of AgriSearch (one of the partners in EuroDairy) and the Agri-Food and Biosciences Institute. Originally established in 1999, the GrassCheck programme aims to provide high quality, up-to-date grass information to assist farmers with grassland management decisions and support improvements in grass utilisation on Northern Ireland (N.I.) livestock farms. Operated by AgriSearch and AFBI, the project monitors weekly grass growth and quality and provides seven and 14 day grass growth rate forecasts to support farmers in managing pasture surpluses and deficits throughout the growing season (Barrett, 2005). Regular grass growth monitoring has been identified as a key mechanism to facilitate improvements in grass utilisation, which in turn, carries a financial benefit for farmers. Work carried out by AFBI has demonstrated that improving grassland utilisation by one tonne per hectare is worth an additional annual profit of £441 ha^{-1} on a dairy farm and £204 ha^{-1} on a beef farm (Mayne, 2016). Historically, GrassCheck has been based on grass plot data. This core data collection has been retained in 2017, however, the project has been expanded to bring in grass growth and quality data from 35 commercial dairy, beef and sheep farms across N.I. Each of the farmer co-researchers have been equipped with the latest GPS rising plate meters to measure grass covers. On-farm grass growth and quality is measured throughout the grass growing season on a weekly and fortnightly basis, respectively. In addition, 24 weather stations have been deployed on these pilot farms to record a wide range of meteorological data from across Northern Ireland. This cutting-edge technology is used to provide farmers with up-to-date information on grass growing conditions and grass quality in their locality to help them make the most of this valuable resource.

To assist the pilot farmers to adopt the technology on their farms, a 'WhatsApp group' was created enabling them to talk with each other and the scientists responsible for the project. This has helped to create a real team spirit around the project.

Throughout the grazing season, weekly bulletins were published in the local agricultural press (Figure 1). This bulletin features grass growth and key weather data in each of the six counties of Northern Ireland. In addition, the project has a dedicated website (www.agrisearch.org/grasscheck) and social media platforms with over 2,000 Facebook followers. In September 2017, three farm walks were held across Northern Ireland to transfer the messages from the first year of this new expanded project. In addition to talks by AFBI livestock scientists, the host pilot farmers spoke about the lessons they had learned from being involved in the process. Another example of farmer-to-farmer learning is the use of social media by the pilot farmers to communicate their experiences of improving grassland management and the lessons learned. The feedback from the farmers involved has been very positive. They had much more confidence in their grazing management skills and several of them were looking to increase stocking rate to utilise the additional grass grown. One key lesson was the considerable variation in grass yields from field to field within each farm. Armed with this knowledge, the farmers are now taking remedial action to improve grass growth in the poorer performing paddocks (e.g. reseeding).

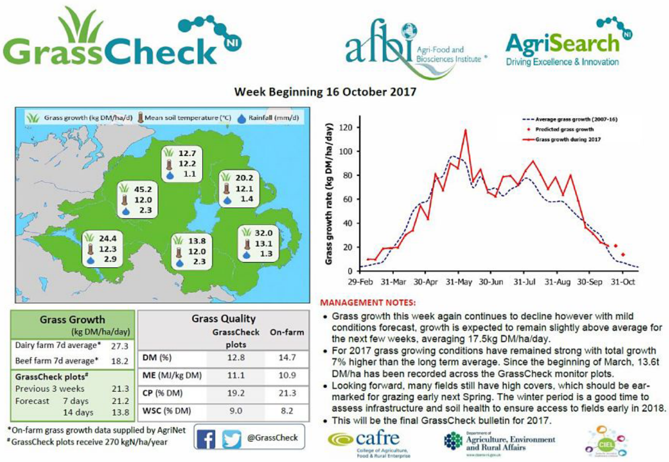

Figure 1. GrassCheck Bulletin (16/10/2017), source: http://www.agrisearch.org/bulletins.

GrassCheck is supported by the Department of Agriculture, Environment and Rural Affairs (DAERA), the College of Agriculture, Food and Rural Enterprise (CAFRE) and the Centre for Innovation Excellence in Livestock (CIEL).

Conclusion

The heart of the ED project are the innovations and how they are transferred from farmer to farmer via the bottom-up approach and by using new technologies like webinars, video magazines, social media, next to 'traditional' media like exchange visits and technical leaflets. GrassCheck is a good example of such new research and extension approaches.

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Dairylink Ireland – 'best use of resources to drive profit'

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Abstract

Dairylink Ireland is an initiative designed to assess how dairy farm businesses north and south of the Irish border will develop with quota barriers dismantled across the EU from the beginning of the project in 2015. With the United Kingdom milk output generally under quota, dairy farmers in Northern Ireland had already increased milk production and expanded facilities prior to 2015. While some growth in scale has been possible for southern producers, more of the focus has been on cost reduction and improving technology. All of this means there are lessons for northern and southern farmers to learn from each other. Dairylink Ireland focuses on farms in the Lakeland Dairies milk collection area, north and south of the border. This unique programme involves a number of organisations; Lakeland Dairies, Devenish Nutrition, Irish Farmers' Journal, CAFRE - Northern Ireland's College of Agriculture Food and Rural Enterprise, Teagasc (Advice, Education and Research in the Republic of Ireland), and the Agri-Food and Biosciences Institute Hillsborough. Features from the farms participating in the programme are published each week in the Irish Farmers Journal to make information and advice widely available and enable knowledge transfer.

Keywords: dairy, profit, farm resource utilisation

Introduction

The focus of the programme is on optimising the use of farm resources for profitable, sustainable milk production in an environment without EU quotas. It is not focusing specifically on expansion or on comparison of farm systems. Instead, it draws on farmer experience and highlights the use of benchmarking and measurement of performance to guide decision making in farm management.

Materials and methods

Six farms were selected from the Lakeland Dairies producer pool to participate for a three year period which started in January 2015 (Table 1). The initial focus was to establish baseline performance information on each individual project farm and to develop a system of data recording and measurement of key performance parameters within each of the farm businesses. Key measurement areas include: production performance, grass growth, heifer and cow weights, grass and forage quality analysis, herd fertility performance and herd genetic information, farm investment and monitoring of cash flow for each project participant.

Table 1. Key performance data for six Dairylink project farms.

	Project start 2015 data	Project end 2017 data
Grass growth (t DM ha^{-1})	9.8	11.7
Nitrogen used (kg N ha^{-1})	173	231
Percentage of area optimal for grass growth (%)	19%	31%
Average herd size (cow no.)	114	135
Milk solids sold (kg cow^{-1})	523	541
Milk solids sold (kg ha^{-1}) (platform)	825	1252
Concentrate supplementation (kg cow^{-1})	1,768	1,485
Calving interval (days)	389	383

Results and discussion

Better utilisation of farm resources to develop a more profitable and sustainable business has been the overarching objective of Dairylink. What areas of the farm business have project farmers focused on and how has this made the production system more sustainable?

Increasing the proportion of grazed grass and forage in the cow's diet lowers the cost of production and reduces dependency on purchased feeds. All project farms have set out to optimise the use of grazed grass in the cow's diet and to meet this aim, project farms have invested in infrastructure including laneways, water systems, land drainage projects and reseeding. This capital investment has been coupled with improved grazing management. Weekly measurement used to guide decisions throughout the grazing season has resulted in more grass growth (average three year increase for project farms is 1.9 t DM ha^{-1}), higher quality grass (D-value > 76%), improved milk quality with more milk solids sold and improved animal health status.

Improving soil fertility with specific focus on soil pH, P and K has resulted in 19.3% more grass growth on average across all project farms. The farmed area with optimal soil fertility for growing grass increased from 19% in January 2015 to 31% optimal in January 2017. Ultimately, improving soil fertility on project farms will optimise this resource, increasing efficiency and facilitating sustainable expansion.

Improving herd fertility has largely been achieved through better recording of breeding data, higher levels of heat detection, selective culling and targeting a more compact breeding period. From a herd genetic perspective, improvement has been achieved through careful sire selection to maximise the impact replacement stock will have on future performance and profitability of each herd. The full impact genetics will have on project farms will only become apparent when significant numbers of replacement stock come into the milking herd. Sires have been selected to deliver higher levels of fertility and ultimately, lower the calving interval on farm. Developing a cow type which is suitable for the production system is an objective on all project farms.

Management of cash flow is a major challenge for a dairy farm business. Prolonged periods of poor weather, animal health issues and periods of low milk prices can add significant pressure resulting in limited cash available for daily operation of a dairy farm. Over the course of the project, a 30% variation in milk price has been experienced by project farmers. While cash flow was difficult to manage when prices were low during 2015 and 2016, this gave project farmers first-hand experience of managing and budgeting cash. It also highlighted the importance of prioritising farm investment into high return areas and building a cash reserve when prices are good, while at the same time continually working towards a lower cost production system.

Sustainability

Each of the farms established a business plan from the start of the project to fully assess the impact of changes to resources used on each farm. Each plan was created to ensure that the business and changes to the business were sustainable in terms of financial viability and the environmental impact. The impacts on labour and animal health and welfare have also been taken into consideration when planning and budgeting ahead for each of the project farms.

Knowledge transfer

The major knowledge transfer aspect to this project is achieved through the linkage with the Irish Farmers Journal, which has a strong focus on technical excellence in farming. A section featuring Dairylink project farms is published each week. This feature article is using real time information and experience from the project farmers, making it available also to a wider audience online and through social media outlets.

Conclusion

Dairylink Ireland project farm businesses have made significant improvements in productivity over the three year period, although more time is needed to fully assess the impact of farm investment and breeding decisions made during the programme. The key drivers for productivity gains across the Dairylink farms have been:

1. Increased grass production and utilisation;
2. Prioritising farm investment to high return areas which will deliver improvements in the overall production system and ultimately, lower the costs of production;
3. Focusing on herd fertility and breeding decisions to deliver genetic improvement within the herd;
4. Managing cashflow and budgeting to build business resilience to price volatility and other factors impacting the business ability to generate cash.

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Accuracy of visual assessment of the plant stand type for the estimation of forage quality

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Abstract

The classification of grassland into four simple plant stand types (rich in grasses, balanced, rich in forbs or rich in legumes), based on the visual assessment of the yield proportion of grasses, legumes and forbs, has proved to be a simple and viable tool for the estimation of forage quality using tabulated values or statistical predictive models. This simple assessment method is currently part of routine knowledge transfer to stakeholders, being mainly farmers and advisors. However, the ability to correctly self-classify the plant stand is sometimes questioned by practitioners. In order to provide sound information on this matter, 632 assessments made by advisors and pupils of agricultural schools were compared to the actual yield proportion values of grasses, legumes and forbs obtained by separating and weighing the three species groups. About two thirds of the samples were correctly classified. The results suggest that not all plant stand types are classified with the same precision and that training level and an assessment of the vegetation after mowing improve accuracy of classification.

Keywords: botanical composition, visual assessment, plant stand type, training level

Introduction

An accurate description of the botanical composition of multi-species grassland in terms of species occurrence and the respective abundance is a time-consuming task. Depending on the planned use of this information, simplified methods may represent a viable alternative. A quick and easy-to-learn method, based on the yield proportion of grasses, legumes and forbs, facilitates the classification of grassland plant stands into four types (G = rich in grasses: more than 70% grasses; B = balanced: between 50 and 70% grasses; F = rich in forbs: more than 50% forbs, legumes less than 50%; L = rich in legumes: legumes more than 50%) and it has been demonstrated to be relevant information for the estimation of the potential forage quality of permanent meadows by means of statistical predictive models (Peratoner *et al.*, 2016). Moreover, this information is needed for the determination of the energy content of forage samples analysed in the lab according to RAP (1999). Therefore, this method is part of routine knowledge transfer to pupils of the agricultural schools and to agricultural stakeholders, comprised mainly of farmers and advisors. However, the individual's own ability to correctly self-classify the plant stand is sometimes questioned by the practitioners taking part in the training events. Indeed, less information is available on the precision achievable by the users and on the underlying factors. This paper aims to provide sound information in this respect.

Materials and methods

A dataset comprising the results of 12 courses held between 2004 and 2017 was analysed. In each course, after a short explanation about the principles of estimation, different plant stands in small quadrats (0.5 × 0.5 m) were visually assessed by the participants. Afterwards, the biomass was mown at a cutting height of 5 cm and the participants were given the opportunity to revise and refine their estimation. The plant material was then manually separated into grasses, legumes and forbs and weighed in the field. These measurements allowed the real yield proportion of the species groups to be computed and the correct classification of the plant stand to be ascertained. To convert the fresh weight measurements into DM proportion values, reference DM contents were used according to Jeangros *et al.* (2001): 194.3

g kg^{-1} for grasses, 126.5 g kg^{-1} for legumes and 127.0 g kg^{-1} for forbs. The species used as a reference (*Dactylis glomerata*, *Lolium perenne*, *Alopecurus pratense*, *Trifolium repens*, *Trifolium pratense*, *Taraxacum officinale*) are among those most frequently found in the training meadows used for the courses. In total, 632 single observations were used. Whilst the number of observations of standing and mown samples were balanced (312 each), there was quite a strong imbalance concerning the training level (112 consultants vs 520 pupils) and the plant stand type (248, 238, 82 and 64 observations for G, B, F and L, respectively). In an initial statistical analysis, the effect of training level (TL; consultant, pupil), the state of the vegetation (SV; standing, mown) and plant stand type (PST; G, B, F, L) as well as their interactions on the dichotomous variable describing the correctness of the assessment of the plant stand type by the participants (1 = correctly assessed, 0 = wrongly assessed) was analysed by means of binary logistic regression. A forward stepwise model was built. A classification cut off of 0.5 was used. An interaction (TL × SV) was included in the analysis after checking for significance with a Pearson χ^2-test.

In a second statistical analysis, the effect of TL and SV was investigated on the absolute value of the difference between the yield proportion of grasses and legumes assessed by the participants and the value obtained from the field measurements. A correct estimation of grasses is very relevant, as two thresholds (50 and 70%) are essential for the classification of G, B and F samples, whilst recognising the actual yield proportion of legumes (threshold of 50%) is essential to correctly classify L samples. The analysis was performed by means of mixed models. The participants were considered as the subject of the repeated measurements concerning the factor SV. An angular transformation was applied to the dependent variable to fulfil the prerequisites of ANOVA. Back transformed estimated marginal means are reported. All analyses were carried out at $\alpha = 0.05$.

Results and discussion

In total, two thirds of the samples (65.7%) were correctly classified by the participants. However, wrongly classified samples were most often assigned to an adjoining category in the sequence G-B-F-L. If such shifts are considered of minor relevance, an almost acceptable classification was achieved in a further 32.4% of the samples (98.1% altogether). The logistic regression detected a significant effect of PST (Table 1).

In comparison to the reference category (G), F and L samples increase the probability of a correct classification by 0.17 and 0.45, respectively. Especially in the case of L, it seems that a high proportion of legumes is more easily recognisable than a high proportion of grasses. Moreover, observers with a higher training level (consultants) were able to take advantage of the possibility of a second assessment of the sample in a mown state. Depending on PST, an increase in the probability of a correct classification of 0.23, 0.21, 0.17 and 0.02 was obtained for G, B, F and L, respectively. Therefore, in the case of experienced observers, a second analysis of the vegetation in a mown state seems to be particularly advisable for plant stands that are relatively rich in grasses.

Table 1. Regression coefficients (b), standard error (s.e.), Wald χ^2, degrees of freedom (df), significance (Sig.) and odds ratio of the factors included as explanatory variables of the correctness of the classification by a forward stepwise binary logistic regression.

Factor	b	s.e.	Wald χ^2	df	Sig.	Odds ratio
Plant stand type (PST)			32.5	3	< 0.001	
Balanced (B)	0.20	0.26	0.6	1	0.453	1.21
Rich in forbs (F)	0.74	0.19	14.7	1	< 0.001	2.10
Rich in legumes (L)	3.35	0.73	21.0	1	< 0.001	28.39
Training level (TL) = consultant by State of vegetation (SV) = mown	0.96	0.34	7.8	1	0.005	2.61
Constant	0.09	0.13	0.4	1	0.508	1.09

TL and SV, but not their interaction, were found to significantly affect the accuracy of estimation of both grasses and legumes (Table 2). As expected, because of the different routine level in performing visual estimations of plant stands, in both cases a slightly better accuracy was achieved by the consultants in comparison to the pupils (grasses: respectively 9.0 vs 12.2% absolute difference to the measured values; legumes: 5.5 vs 10.1%). Mowing the vegetation provided another slight improvement of the estimation accuracy (grasses: 9.8 vs 11.2% difference for mown and standing vegetation respectively; legumes: 6.7 vs 8.6%).

Table 2. ANOVA table of the effect of training level and state of the vegetation on the accuracy of the assessment of grasses and legumes expressed as the absolute difference between the estimated value and the measured one.

Factor	df	Grasses		Legumes	
		Fisher's F ratio	Sig.	Fisher's F ratio	Sig.
Training level (TL)	1	5.59	0.019	11.54	0.001
State of vegetation (SV)	1	5.37	0.021	17.62	< 0.001
TL × SV	1	0.68	0.410	0.031	0.860

The two analyses detected two slightly different patterns of effects. Possible explanations are the different nature of the dependent variables as well as the different statistical models tested: PST was omitted in the mixed model analysis due to its strong relationship to the yield proportion of grasses and legumes; in the logistic regression it could not be accounted for in the repeated measurements. However, the improvement in the accuracy due to the training level as well as the advantage of a second assessment of the mown vegetation are elements common to both analyses.

Conclusion

Even a short period of training results in an acceptable accuracy of visual assessment of the plant stand type but the precision should be enhanced by routine estimation and can be further improved by a closer look at the mown vegetation.

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Increasing beef production from grass and grazed forage by using farmers as mentors

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Abstract

Four beef farmers who wanted to improve their grazing management (improvers) were recruited across England and paired with local farmers, who had already improved their grazing techniques (mentors). Informal training was provided by the mentors with regular visits and conversations. Two grassland consultants provided technical support to the improvers and facilitated the regular events that were held on the improvers' farms. The activity covered two grazing seasons with the aims of reducing the number of days cattle are housed, increasing stocking rates across the grazing platform and improving growth rates from grazing and silage. During the first grazing season, rotational grazing was introduced on each of the improver farms. Fields were split into smaller paddocks using temporary electric fencing and weekly grass growth measurements were taken using either a plate meter or compressed sward stick. Through rotational grazing, grassland utilisation increased by as much as 30% on the improver farms. The next focus was to extend the grazing period and reseed any poorly performing paddocks. All four improver farms have made significant improvements to their grazing management and through the approach used have developed a community of interested producers around them.

Keywords: grazing, beef, rotational grazing, utilisation, mentors

Introduction

The potential for beef cattle to achieve high growth rates from grass and grazed forages is well known but rarely achieved on English farms. Maintaining quality and quantity going into the summer is a key focus area, as is earlier turnout. Unlike other ruminant sectors, very few beef producers measure and record grass growth.

The objectives of this project were to highlight the potential of grass and grazed or conserved forage for beef cattle production and to provide practical guidance on how current grazing management can be improved. Local farmers who have already improved their grazing systems were used as mentors with the ambition to increase uptake and implementation of knowledge.

Three targets were established at the beginning of the project to target the key areas of poor performance and profitability in beef systems. The targets were to reduce the number of days cattle are housed by 20%, to increase stocking rate across the grazing platform by 20% and to achieve a 10% increase in cattle growth rates over a 12 month period.

Materials and methods

Four English beef producers who were maximising the use of grass and forage were identified (mentors) and were paired with four beef producers who wanted to improve their grazing management (improvers) (Table 1). The mentors and improvers were recruited through AHDB. Two grassland consultants (Marc Jones and Charlie Morgan) worked with two pairs each to come up with specific targets and activities

Table 1. Summary of systems for improvers and mentors.

Pair	Name[1]	Location	System
1	Graham Parks*	Cheshire	finishing 200 dairy × cattle
	Andrew Crow	Shropshire	120 suckler cows, plus finishers
2	Matt Pilkington*	Warwickshire	grass-based dairy system
	Tim Phipps	Northamptonshire	80 suckler cows, plus finishers
3	Catherine Pickford*	Somerset	300 spring calving NZ Jersey × Friesian cows
	Matthew House	Somerset	120 suckler cows, sells as stores
4	Stephen Thorne*	Devon	90 suckler cows, sells as stores plus 150 dairy cross calves
	Rob and Liz Priest	Devon	60 suckler cows, plus finishers

* indicates the mentor.

for the improvers. All the improvers established rotational grazing systems, used a plate meter to assess pasture cover and entered data into Agrinet farm management software.

Progress was tracked over two grazing seasons (2016 and 2017) with activity documented and costs and benefits of the changes collated. Cost of production information for all improver farms were collected over the length of the project.

The consultant visits were made quarterly with the mentor also in attendance, with more informal visits between the mentor and improver over the season. During the first visit to the improver farms, soil tests and forage analysis were taken with the results being used to develop a nutrient management plan and winter rations respectively.

During the first grazing season, two of the mentor farms hosted an event with the other two hosting an event in year two of the project. The improver farms hosted an event both years, with at least 30 people attending each event. Case studies from the events and the farmers were used as part of wider knowledge exchange campaigns, for example, AHDB's Grazing Club e-newsletter, Better Returns Programme bulletin and R&D review.

Key performance indicators (KPI) related to grassland management and profitable beef farming have been evaluated and appropriate data has been captured on the farm. These include tonnes of dry matter of grass, silage and forage crops produced per hectare, kilograms of liveweight produced per hectare, fertiliser use per hectare, kilograms of concentrates fed per animal, number of grazing days and profitability of the beef enterprise per hectare.

Results and discussion

Currently the data for all the targets and KPIs for all four improver farms for both grazing seasons are not available, but will be for June 2018.

During 2017, one of the improvers managed to increase in output per hectare by 40% as his stocking rate has increased from 1.62 livestock units per hectare (LSU ha^{-1}) to 2.33. He had grown 13.1 t DM ha^{-1} (from January to the end of September) with the ambition to push yields up further.

The support network of the consultants and mentors have developed the confidence of the mentors and helped them evaluate their activity. The use of the management software tool has provided additional information and has been used to benchmark performance between the farms. It is likely that the original targets (reduction of 20% in number of days cattle are housed, a 20% increase in stocking rate across the grazing platform and a 10% increase in cattle growth rates over a 12 month period) will be achieved on all farms.

The events and the knowledge exchange activity throughout the project has built up the awareness of the project but have been challenging as the complete set of results are not available. The events have focused on demonstrating activity, understanding what the attendees currently do and highlighting future plans. More than 400 farmers have attended the events over the two grazing seasons and the articles have been distributed to more than 30,000 levy payers.

Once the results are available, a blueprint for beef production from grass and forage will be developed and communicated widely. The original improver farmers will also be used as mentors in the next phase of the project to ensure that the benefits are communicated further.

Conclusion

The approach of providing support to farmers who want to change their grazing systems through the provision of mentor farms and occasional consultant visits has improved performance from grass and grazed forage. This has been combined with knowledge exchange activity throughout the project to maximise impact, with further work planned when the full results are available.

Acknowledgements

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Grass10 – an extension campaign to improve the level of grass production and utilisation

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Abstract

The level of grass utilised by grazing livestock is known to be positively related to the profitability of grass-based production systems. Irish statistics demonstrate that, on average, 7.8 and 5.6 t DM ha^{-1} yr^{-1} was utilised on dairy and non-dairy farms, respectively, during 2016. However, it is also known from the PastureBase Ireland database that many farms can grow in excess of 13 t DM ha^{-1} yr^{-1} and can utilise approximately 10 t DM ha^{-1} annually. The number of grazings achieved per paddock is also known to increase as pasture production and utilisation increases. Therefore, there is an opportunity to greatly improve the level of grass grown and utilised at farm level. Grass10 is a new grassland campaign whose objective is to increase the level of grass utilised on Irish farms to 10 t DM ha^{-1} yr^{-1}. This campaign will aim to improve the components that influence the level of grass production and utilisation. These components are soil fertility, grazing management, grazing infrastructure, grassland measurement and sward composition. This improvement will be achieved through the use of on-farm events, social media, other media channels and industry open days to improve knowledge transfer and adoption. The Grass10 campaign enables a greater focus to be placed on grazing by the industry. The campaign is supported by industry shareholders and the delivery of industry achievements are monitored by key performance indicators.

Keywords: grass, grazing, extension, grass utilised

Introduction

Grazed grass is the cheapest and most widespread feed for ruminant production systems in Ireland (Finneran *et al.,* 2010). As an abundant natural resource, grass provides Irish farming with a significant competitive advantage for milk and meat production (Byrne *et al.*, 2015). Our competitive advantage in milk production can be explained by the relative cost of grass, silage and concentrate feeds (O'Donovan *et al.,* 2011). An analysis of farms completing both grassland measurement and financial analysis demonstrated increased profit of €180 ha^{-1} (Dillon, 2016) and €105 ha^{-1} (Crosson *et al.,* 2015) for every 1 t DM ha^{-1} increase in grass utilised on dairy and drystock farms, respectively. Currently, it is estimated that about 8 t DM ha^{-1} yr^{-1} is utilised nationally on dairy farms and about 5.5 t DM ha^{-1} yr^{-1} on drystock farms (Teagasc, 2016). Data from the best commercial and research farms indicate that the current level of grass utilised can be significantly increased (to in excess of 10 t DM ha^{-1} utilised). So, there are major improvements required in areas of pasture production and utilisation. Increasing the number of grazings per paddock is a key aspect of increasing the level of grass utilised. In a recent analysis of grazing performance from PastureBase Ireland, there was a strong relationship (r^2 = 0.73) between the level of annual grass DM production and the number of grazings achieved (O'Donovan and Maher, 2015).

Grass10 campaign

Grass10 is a four-year campaign recently launched by Teagasc to promote excellence in grassland. The Grass10 campaign will play an important part in increasing grass growth and utilisation on Irish grassland farms, thereby improving profitability at producer level of Irish beef, dairy and sheep production systems. The objective of the campaign is to achieve 10 grazings per paddock per year, utilising 10 tonnes grass DM ha^{-1}. In order to achieve this objective, significant change in on-farm practices will be required, specifically: improved grassland management skills, improved soil fertility, improved grazing infrastructure, improved sward composition and increased grass measurement. To ensure the success of this campaign, it will be necessary to measure trends in a range of performance indicators. An indicative list of key performance indicators (KPI) for this campaign is provided in Table 1.

Delivery

Grass10 will develop a body of agreed resources tailored to the needs of various user groups. Testing of the various resources with farmer groups is critical for success. It is expected that a key output will be a Grass10 manual and a Grass10 website which will be used as a management and extension tool.

Awareness

A campaign working group has been established to develop a comprehensive communication strategy that will highlight Grass10 to all target audiences. It is critical that key messages from the resources developed by Grass10 reach the target audiences. It is envisaged that five different communications channels will be used:

1. events (including training courses, discussion group meetings, farm walks, open days);
2. publications (including manuals, newsletters, articles);
3. website (the grassland section of the Teagasc website to be refreshed, updated and promoted; other media channels to be used to promote website awareness);
4. media (including farming publications, other websites, press releases, advertising, national radio/ TV, local radio/ TV, etc.); and
5. social media (including Twitter, You Tube clips, podcasts, live streaming of events, etc.).

It is important to remember that the best method of extension is to use multiple methods (Vanclay, 2004). This approach to extension is required to deliver the message to the diverse range of farmers, advisers, etc. and to reinforce the message in different ways.

Building capacity

This aspect of Grass10 will focus on up-skilling all 'players' (farmers/extension, etc.) in the industry. A key objective of the Grass10 programme will be to build the capacity of the various advisers/consultants involved in providing grassland advice to Irish farmers. These are in a unique position to advise, inform and influence farmers. Training workshops will increase their technical capacity and equip them to increase their usage of PastureBase Ireland. Technologies which enable data-informed decision-making on the farm can help to increase farmers' confidence and greatly improve grassland management (Hanrahan *et al.,* 2017).

Table 1. Key performance indicators (KPI) for Grass10 campaign.

Suggested KPI: campaign performance measurement (outputs)	
1.	No. of farmers using PastureBase Ireland
2.	No. of farmers completing 25 or more grass cover measurements year^{-1}
3.	No. of advisers/consultants with greater than 10 users on PastureBase Ireland
4.	No. of grazing events held
5.	Level of website/social media usage
Suggested KPI: farmer performance measurement (impacts)	
1.	Grass DM utilised ha^{-1} – annual and seasonal
2.	No. of grazing rotations completed
3.	Trends in soil fertility indices
4.	Level of reseeding completed year^{-1} (annual sales of grass seeds)
5.	Level of animal output (kg ha^{-1})

As Ireland's competitive advantage is in our ability to grow grass, it is vital that Irish agriculture collectively strives to maximise the untapped potential that exists. Grass10 will provide a means to allow the industry to set clear, ambitious targets and encourage the achievement of the targets set through the 'Grassland Farmer of the Year' competition in association with key external stakeholders.

Conclusion

The level of grass utilised by grazing livestock is known to be positively related to the level of profit generated by the farm. Significant change is required in the grassland management practices of Irish livestock farmers. Grass10 is a new campaign whose objective is to increase the level of grass utilised to 10 t DM ha^{-1} and increase the number of grazings per paddock per year to 10. This campaign will aim to improve the components that influence the level of grass production and utilisation. Campaign delivery and industry achievement are monitored by key performance indicators.

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How French Chambers of Agriculture contribute to maintaining and developing grasslands

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Abstract

The French Chambers of Agriculture are self-governing public bodies, managed by elected farmers. Their role is to represent the farmers to local, regional and national authorities and to offer a range of services to farmers and other rural stakeholders. As regards this latter point, they provide individual and collective advice to farmers on the production and use of grasslands through tools, methods and various training sessions. In particular, several chambers regularly provide 'grass reports' collecting specific information for farmers about how grass is growing, linking to local areas and providing advice about how to handle grass production. Some chambers developed a 'grass and forage' network gathering advisors and farmers who exchange information and knowledge through demonstration activities and peer-to-peer learning. Visits to research centres leading experiments on grass and grazing management are also available within this network. Farmers of this network benefit, not only from the external vision of the advisor, but also from the experience of the other farmers. One chamber has also produced a strategic tool designed for farmers, named 'Prev'Her', which is an app to help with handling grazing periods during spring and summer.

Keywords: development, transfer, advice service, development program

What is a Chamber of Agriculture in France?

The network of French Chambers of Agriculture (FCA) consists of 89 'departmental' chambers, 13 regional chambers and 1 national chamber. With 4,200 elected farmers and more than 8,000 permanent employees, the network has a great strike force on the field. It works at grassroots level with farmers, farming workers, foresters and local authorities in the interests of the agricultural sector by:

- supporting and advising farmers;
- developing agronomy and good environmental practices;
- developing rural areas.

The French State entrusts the Chambers of Agriculture with five public services including livestock identification, business formalities, Agricultural Register, apprenticeship and help for young farmers. The network services meet the changing needs of enterprises: transmission and setting-up, optimisation and management of crops and businesses, farm strategy, marketing and support on regulatory issues. Advisory and training activities are certified by a quality certification.

The FCA's two main roles are:

- a technical role: to provide a wide range of services to farmers and to other rural stakeholders. The French Chambers of Agriculture are self-governing public bodies which are recognised by the French rural code and French law;
- a consultative role on agricultural and rural issues.

The FCA also manage experimental stations and are involved in many programs of research with the National Institute of Agronomic Research (INRA) among other partners (APCA, 2017). In this context, using individual services, group animation, group training, etc., the network is the major actor for transfer and exchange of knowledge between research and practice.

What sources of information do advisors use?

French Chambers of Agriculture use many different ways to ensure knowledge is transferred to the farmers. But first, where does the information come from? As managers of experimental stations, the FCA produce practical results which are more or less directly available for the network. For example, the Chamber of Aveyron has published a short article on an experimentation conducted between 2000 and 2002 on the experimental farm of Cambon on its website. The experiment was about the interest of mixing bovine and ovine grazing regarding parasitism management (Chambre d'Agriculture de l'Aveyron, 2002). The study was followed and approved by a scientific committee composed of representatives of the Chamber of Agriculture, the Agricultural School of Saint-Affrique, INRA, Livestock and Vegetal Institutes, National Schools of Veterinarian Sciences and Agronomy, Massif Central Organic Centre and other local stakeholders. Soon, all the publications of the FCA will be gathered on an on-line national documentary centre that will greatly increase dissemination of the results of each experimental farm within the network. In some areas, the relationships between research and the Chambers are really close. Besides the experimental farms, there are some research programs in collaboration with INRA and some regions have established clusters, these organisations are real opportunities to develop and keep a close relationship between research and development to ensure knowledge transfer. In some clusters, there are also stakeholders from local industries and businesses interested in grasslands. Some Chambers are also involved in larger projects such as European projects. For example, the Chambers of Normandy, Centre Val de Loire, Pays de la Loire and Vosges collaborate with APCA in the Inno4Grass project. Led by Grünlandzentrum (Germany), the project has an overall objective to identify, analyse and disseminate innovations that could help improve grassland use, management and valorisation within Europe. Many advisors also participate in scientific meetings, such as the 'Journées de l'AFPF' (AFPF, 2017) where they keep themselves up-to-date about scientific results and meet with researchers. Besides their everyday-bibliography work, the advisors of the Chambers have thus many opportunities to know about the latest research results and to maintain relations with the researchers. Finally, throughout the National Livestock Network 'INOSYS' and other research programs detailed above, the advisors have access to 'references' which allow them to benchmark the farmer's farming system results at various levels with optimised systems in order to quickly identify improvement opportunities.

How is knowledge transferred?

The Chambers of Agriculture provides individual and collective advice and follow-ups through paid or free services directly delivered to the farmer. For example, the Chamber of Orne (Normandy) offers around 19 various services about grassland on stocktaking and management of forage stocks, variety selection on seedlings, grassland renovation, mechanical maintenance and weeding. Moreover, the Chambers of Agriculture enforce a regional Observatory of the grass growth in at least seven regions of France and the results are transferred through regular (mostly weekly) newsletters directly to farmers and available on their websites. These newsletters are tools to help farmers to make better grassland management decisions and enhance grasslands by giving direct advice based on knowledge of both grass growth and weather forecasts. Another tool to help management decisions has been developed by the Chambers of Limousin; 'Prév'Her' is an app to help affect grasslands and organise rotational grazing using farmer's data to calculate animal requirements, areas to mow, areas to graze, stocking rates, batching, allocation of the areas for each batch of animals, etc. (Feugere, 2013).

Knowledge transfer can thus be done piece by piece but it is also organised through programs that forecast various ways of giving the farmers the information. For example, in the Central Massif, a research program, called AEOLE, is led by the SIDAM (group of 17 Chambers of Agriculture) on permanent grasslands and heath lands. In this project, a very precise typology of grassland diversity has been defined which gives the agricultural values of each grassland, the environmental and ecological services yielded and the quality of the forage that can be produced from it. References are also created. A multifunctional diagnosis of the forage system (DIAM), created for dairy farms, will also be adapted to all ruminants farms. This software evaluates the services yielded by the diversity of the permanent grasslands of a farm, not only on the agricultural level, but also on ecological and environmental levels. To provide information about the impact on product quality, very clear indicators will be defined. In addition, a new method is currently being developed to find a playful way to transfer the typology and the other results to farmers, advisors and other stakeholders efficiently.

Training provides another avenue to transfer knowledge. All chambers of agriculture are able to propose training sessions and training programs to farmers, collaborating partners, familial help, farm workers and future farmers. Thus, there are training sessions about how to manage grasslands, how to operate grasslands to meet the agronomic potential of the soil and on the innovative techniques. Group sessions, individual follow-up and collective visits to farms are all different ways to provide the message. Last but not least, the farmers are invited in each region to technical meetings on a farm. These days aim to demonstrate a practice and invite the farmers to discuss it from their own experience while the scientific results are brought by the advisors.

Conclusion

Their place in the landscape of the various stakeholders in the farming sector makes the French Chambers of Agriculture a major actor in farm development and knowledge transfer. By getting involved in research programs, participating in scientific meetings, developing their own references from the field, the advisors link research and practice. Through direct services, training programs, open technical meetings and other tools to help decision making, the Chambers of Agriculture ensure knowledge transfer to directly serve the farmers. Ultimately, the better that farmers are informed about how to use grasslands, the more durable grassland production can be in the future.

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Better Farm Beef Challenge Northern Ireland

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Abstract

This programme is a collaborative venture between the College of Agriculture, Food and Rural Enterprise (CAFRE), the Irish Farmers' Journal and ABP Food Group and is now entering its seventh year and third phase of development. The central theme is improving farm profitability by adopting established best practice and new technologies in grassland management with the support of a CAFRE development adviser. There are ten participating farmers located throughout Northern Ireland (NI) and each farm has a different challenge to overcome. Participating farmers have been selected based on their attitude to continuous development and potential for improvement. Most participants were at 'average' performance levels based on CAFRE financial benchmarking at the beginning of the programme. However, previous participants who entered phase 2 of the programme in 2014 have seen an average increase in Gross Margin (GM) of £517 ha^{-1}. Tools used to improve grassland management, herd fertility and business performance include knowledge transfer, technology adoption, facilitated peer-to-peer learning and also mentoring support from previous programme participants. Benefits are disseminated throughout the wider suckler beef farming community through farm visits and regular features in the Irish Farmers' Journal.

Keywords: BETTER Farm, stocking rate, gross margin, grass utilisation, herd fertility, business management

Introduction

Benchmarking data compiled by CAFRE over the past decade has shown significant differences in profitability on NI suckler to beef farms, even across farms of similar land types. However, one clear correlation is that of stocking rate and GM ha^{-1} (Figure 1). Many studies have shown grazed grass to

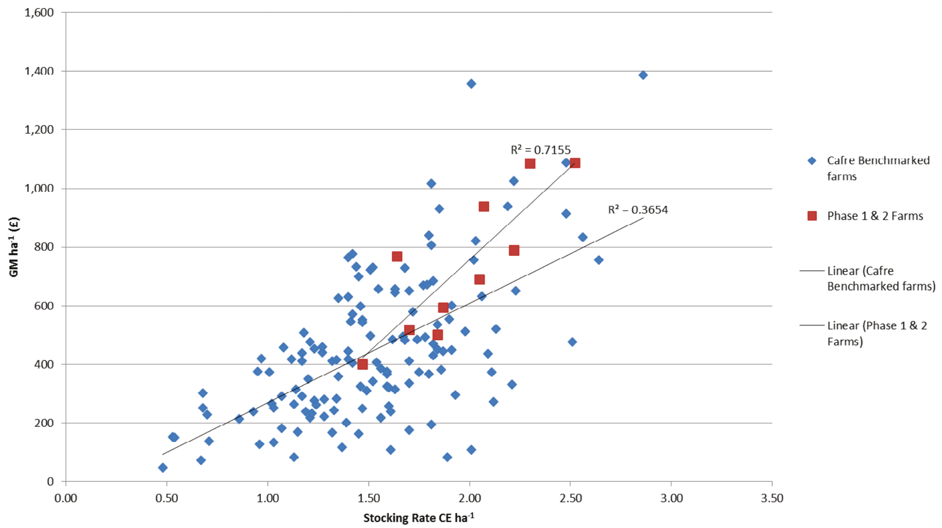

Figure 1. The relationship between stocking rate (cow equivalents ha^{-1}) and gross margin (£ ha^{-1}) on Better Farm Beef Challenge Northern Ireland Farms.

be the cheapest source of feed for ruminants (Frame and Laidlaw, 2011). However, there is a relatively low uptake of technologies to improve the utilisation of grazed grass on suckler beef farms in NI. Those farmers participating in the Better Farm Beef Challenge NI were encouraged to adopt technologies which would improve the utilisation of grazed grass and, therefore, reduce the cost of producing beef on each farm and also allow a higher stocking rate to be maintained.

Materials and methods

Phase I of the Better Farm Beef Challenge NI was delivered from February 2011 until February 2014 and included ten participating farmers. Phase II ran from February 2014 until February 2017 and also included ten participating farmers, five of which had also participated in Phase I. To ensure participating farms were representative of the challenges presented by different land types and microclimates across NI, at least one farm was recruited from each county with a range of farm sizes (32 - 194 ha). All farmers selected had a desire to improve the profitability of their suckler beef enterprises and a positive attitude to change. The core objective on each farm was to improve its long term profitability. The key measure used to assess levels of improvement across farms was GM ha^{-1}. Fixed costs were not included as these are often distorted by each farm's stage of development. A baseline GM ha^{-1} was established for all farms using the calendar year prior to joining the programme.

To achieve an improvement in each farm's GM, detailed farm plans were developed and agreed with both the farmer and a dedicated development adviser. The central theme of these plans was the adoption of technologies to increase the stocking rates on farms through better utilisation of grazed grass, improving herd fertility, calving pattern and reducing age of first calving, the strategic use of imported feedstuffs and a planned approach to improving animal health.

Focusing specifically on improving utilisation of grass, each farmer used AgriNet management software to create a weekly grass 'wedge' for different grazing areas. This enabled grass supplies to be more accurately budgeted using paddocks designed to match potential stock numbers and stocking rates. This was to ensure that cattle entered paddocks when grass was at its optimum pre-grazing cover (2,800 to 2,950 kg total DM ha^{-1}). This allowed grass to be better utilised whilst also maximising animal performance.

Results and discussion

From a baseline stocking rate taken over the 2010 calendar year (1.67 Cow Equivalents [CE] ha^{-1}), the five original participants who also entered Phase II of the programme achieved an average increase in stocking rate of 0.81 CE ha^{-1} (48.5%). Similarly, from a baseline stocking rate taken from 2013, the year prior to Phase II farms joining the programme, the stocking rate on these five farms increased from 1.71 to 2.09 CE ha^{-1}(a 22% increase).

On Phase I farms, GM ha^{-1}increased from £360 ha^{-1} in 2010 to £960 ha^{-1} in 2016. GM ha^{-1} in Phase II farms increased from £365 ha^{-1} in 2013 to £882 ha^{-1} in 2016. Although there is a strong positive correlation between stocking rate and GM ha^{-1} (Figure 1), not all variation is explained and, therefore, an increase in stocking rate does not guarantee improved profitability. Due to fluctuations in the value of outputs (beef price) and input costs (fertiliser, veterinary, concentrates), it is difficult to determine the precise influence of these variables on changes in GM ha^{-1}. As a result, each of the farms was benchmarked against the average, and top 25% of CAFRE benchmarked farms. The results (displayed in Figure 2) clearly show the progress in GM ha^{-1} on both Phase I and Phase II participating farms compared to those farms in the average and top 25% categories during the same time period.

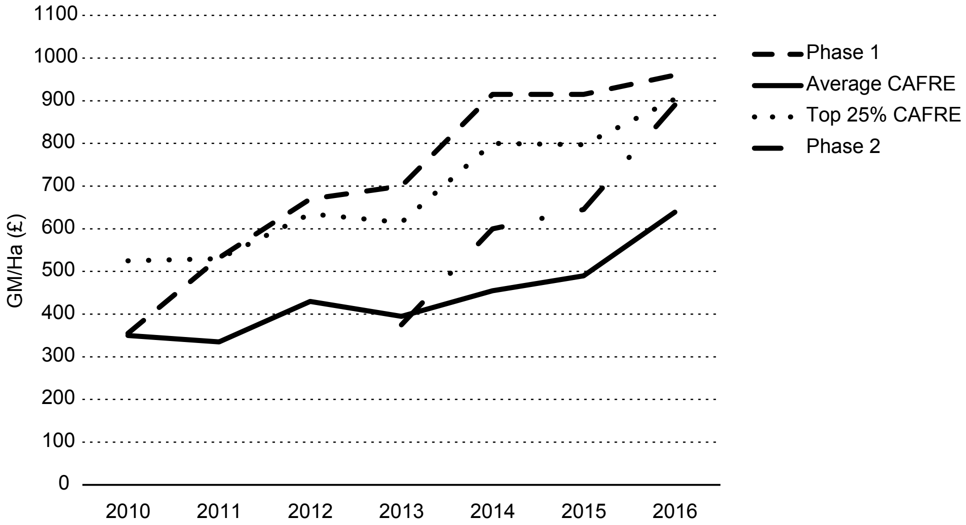

Figure 2. Better Farm Beef Challenge NI Phase I and II GM ha^{-1} and CAFRE benchmarked suckler-beef average and top 25%.

Conclusion

The results to date from the Better Farm Beef Challenge NI have shown that there is significant scope to improve the GM ha^{-1} on suckler beef farms across NI. There is a positive correlation between GM ha^{-1} and stocking rate as demonstrated by CAFRE benchmarking results although an increase in stocking rate alone is not always a guarantee of improved margins. However, data collected over two phases of the Better Farm Beef Challenge NI has demonstrated where an improvement in stocking rate is achieved through improvements in grazing management and grass utilisation, there is scope to realise improvements in suckler beef farm GM.

Acknowledgements

We acknowledge the input of CAFRE, Irish Farmers' Journal, ABP Food Group and participating farms.

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Developing TechnoGrazing beef systems in England

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Abstract

TechnoGrazing systems use bespoke electric fencing and water equipment to divide an area of land into precisely defined lanes. These are sub-divided into cells to create a grazing rotation, the length of which can be quickly adjusted to suit requirements while maintaining access to water. Two TechnoGrazing systems were designed and installed by Precision Grazing Ltd on two beef farms near the Cornwall/Devon border in the south west of England. System size ranged from 4.77 to 6.47 ha covering a mixture of soil and pasture types. Set-up cost varied from £276 to £420 per hectare including design, equipment, installation and training. The two farms involved in the trial grew 21.7 t and 13.3 t DM ha^{-1} with a utilisation rate of 74 and 86% respectively, calculated by Farmax Performance Monitoring tool. The amount of dry matter (DM) produced per year on a typical English beef farm using set-stocking is estimated by AHDB at 8.5 t DM ha^{-1} with 50% being utilised. The TechnoGrazing systems grew 56 to 250% more DM due to improved grazing management. Having the correct stocking density meant the animals were able to consume the surplus grass which is normally wasted, which led to higher utilisation.

Keywords: TechnoGrazing, beef, stocking density, production per hectare

Introduction

In England, there is a growing interest in increasing the intensity of grazing systems, partially due to an increased focus on profitability and resource use efficiency. It has been suggested that set stocking systems only utilise around 50% of the grass grown (AHDB, 2016a), with higher utilisation recorded as fencing and number of livestock movements increases, for example, around 75% for rotationally grazed pastures (AHDB, 2016a). Recent work in Ireland by Teagasc has estimated that if annual grass utilisation is increased by 1 t DM ha^{-1}, there is a benefit of €105 per hectare for drystock farmers (Teagasc, 2017).

TechnoGrazing was developed in the 1980s by Harry Wier, director of Kiwitech International Limited. TechnoGrazing Systems use bespoke electric fencing and water equipment to divide an area of land into precisely defined lanes with great efficiency. The lanes are then sub-divided into cells to create a grazing rotation, the length of which can be quickly adjusted to suit requirements whilst maintaining access to water.

The aim of this project was to demonstrate the potential of TechnoGrazing systems for the first time in England.

Materials and methods

Two TechnoGrazing systems were designed and installed by Precision Grazing Ltd on two beef farms near the Cornwall/Devon border in the south west of England. System size ranged from 4.77 to 6.47 hectares covering a mixture of soil and pasture types as shown in Table 1. Set-up cost varied from £276 to £420 per hectare including design, equipment, installation and training. The number of lanes, cells and cell area were decided by Precision Grazing Ltd after reviewing the requirements of the farm and the topography of the field.

Table 1. Details of the two farms involved in the TechnoGrazing demonstration.

	Higher Trevallett farm	West Panson farm
Size (ha)	4.77	6.47
Number of lanes	4	4
Number of cells	64	64
Cell area (ha)	0.075	0.101
Soil type	Medium loam, free draining	Medium to clayey loam
Pasture type	Permanent	Temporary
Stock class	Dairy cross heifers and steers	Black Limousin heifers and steers
Age at turn-out on to TechnoGrazing system	14 months	11 months
Average stocking rate (number of cattle per ha)	7.47	6.09
Average stocking rate (livestock units per ha)	5.55	3.88

All animal weights were collected by the farmer following four hours of fasting to reduce the impact of changes in gut fill. Pasture cover was measured weekly by rising plate meter. The grass supply and utilisation was calculated from the weekly pasture cover assessment and the demand was calculated by the Farmax Performance Monitoring tool. Results were sent to Precision Grazing Ltd who analysed the information and provided bespoke instructions by text message to the project member defining the allocation (number of cells per day) for that week. Additional support was provided by phone and systems were visited every six weeks.

Any surplus was controlled by increasing the number of cells allocated per day to reduce the rotation length and therefore, reduce pasture cover, with any deficiencies managed by reducing the number of cells allocated each day to increase the rotation length and pasture cover.

Results and discussion

The focus of the pasture management has been to capitalise on the periods of surplus feed ensuring animal intakes are maximised whist maintaining quality and keeping sufficient canopy to grow enough grass to meet demand.

The average grass DM grown on the average farm using set-stocking is estimated at 8.5 t DM ha^{-1} with 50% utilised (AHDB, 2016a). The TechnoGrazing systems grew more DM (Table 2), which led to the average stocking rate (Table 1) being two to three times higher than the comparable English average of 1.9 livestock units per hectare from AHDB's Stocktake report (AHDB, 2016b).

The calculated utilisation rates of 74 and 86% (Table 2) meant that less grass was wasted compared to the suggested utilisation rate for set-stocked systems of 50% (AHDB, 2016a).

Table 2. The pasture production on the TechnoGrazing demonstration sites.

	Higher Trevallett farm	West Panson farm
Dry matter production (t DM ha^{-1})	21.67	13.26
Dry matter utilised (t DM ha^{-1})	15.96	11.40
Utilisation (%)	74	86
Fertiliser applied (kg N ha^{-1})	104	96

For the systems, the average daily live weight gain (LWG) was 0.74 or 0.8 kg (Table 3). Overall, the combination of extended grazing period, good average daily LWG and high stocking rate resulted in double the live weight production per ha compared to industry average for 16 to 24 month beef finishing system (AHDB, 2016b). This led to gross income's estimates of £1,531 to £1,718 per hectare, with comparable industry figures being £668 per hectare (AHDB, 2016b).

Table 3. The performance of the TechnoGrazing demonstration sites.

	Higher Trevallett farm	West Panson farm
Total animals	42 cattle	45 cattle
Mean number of days in system	154	201
Mean daily liveweight gain (kg d^{-1})	0.74	0.80
Mean total weight gain (kg)	4,786	7,236
Production (kg live weight ha^{-1})	1,074	957

Conclusion

On these farms, TechnoGrazing has shown to substantially increase the production from pasture compared to average industry figures for a similar system combined with higher potential margins per hectare.

Acknowledgements

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HerbValo – a method for calculating annual pasture utilisation by dairy cows at paddock level

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Abstract

Better knowledge of pasture utilised by grazing dairy cows (in t DM ha^{-1} year (y)$^{-1}$) would help farmers to analyse and improve their grazing management. This is the aim of HerbValo, a generic method designed to be used on commercial farms. This method combines recording grazing or cutting events at paddock level all year round and a spreadsheet for calculating pasture grazed or harvested per rotation and year. For the grazing events, the calculation takes into account the number of grazing days (herd size × residence time) at each rotation and the average daily intake per animal, estimated from a simple description of herd characteristics, supplements, pasture type and quality, and grazing severity. No pasture measurements, such as pre- or post-grazing pasture heights, are required. A large 19-year experimental database (Le Pin-au-Haras) was used to calculate the intra- and inter-annual variability of pasture utilisation, according to weather conditions or management practices. Pasture utilisation averaged 9.4 ± 1.32 t DM ha^{-1} y^{-1} and ranged from 6.7 to 12.5 t DM ha^{-1} y^{-1} depending on paddock, year and management. Using this tool on a number of commercial farms will enable the provision of regional references on pasture utilisation by grazing livestock.

Keywords: grazing, dairy cow, pasture utilisation, methodology

Introduction

In grazing systems of Western Europe, high pasture utilisation rate is a key point for increasing milk or milk solids production and profit per hectare, through reduction of feeding costs (Ramsbottom *et al.*, 2015). It is always difficult to estimate the quantity of pasture used annually by grazing herds, particularly on commercial farms where no field measurements are made, making the comparison with other harvested forage resources difficult. Moreover, at grazing, farmers decisions, and particularly stocking rate or grazing severity, have a large effect on pasture utilisation and milk production per hectare (McCarthy *et al.*, 2011). A collaborative project between research and extension services within the French network Réseau Mixte de Technologie (RMT) Prairies Demain led to the development of a simple and robust method called HerbValo, to be used by farmers themselves, on selected paddocks, for estimating pasture utilisation rate on an annual basis. Specific versions have been developed for dairy cows, suckling cows, and dairy goats (Delagarde *et al.*, 2017). The development of versions for sheep and equine is ongoing. The aim of this work is to describe the HerbValo method for dairy cows, and to analyse a large multi-year dataset from the INRA experimental farm of Le Pin-au-Haras (Normandy, France) to determine the sources and range of variation in pasture utilisation rate according to year, season, and grazing management.

Materials and methods

HerbValo description

Pasture utilisation (t DM ha^{-1}) is calculated per paddock, at each event (grazing or cutting), and then summed to calculate seasonal or annual pasture utilisation. At each grazing rotation the calculation is based on the product between the number of grazing days per ha (herd size × residence time per paddock area) and the pasture intake of the average cow in the herd (kg DM d^{-1}). Pasture intake is calculated according to the principles of the INRA feed unit system adapted to grazing situations (INRA, 2010), taking account of cows, pasture and supplement characteristics, grazing severity and daily access time to pasture. Except for the quantity of each supplement eaten and the pasture yield at each cutting event, no 'numeric' data are required. Animal (breed, milk production, body size), pasture (type and quality, characterised by color, from green to yellow), and grazing severity (from lax to very severe) are characterised by selecting a value from a list of three to four predefined classes. Classes were defined to be easily selected by a farmer or an advisor, and to provide approximately a 5% difference in intake between two consecutive classes. Cows may receive any quantity and number of supplements, substitution rates being calculated according to supplement type and grazing severity. More details about principles, equations, parameters and accuracy of the method by comparing with the predictions from the GrazeIn model are provided by Delagarde *et al.* (2017). Paddocks and herd are described once a year, and events are described at each rotation, on paper sheets. Calculations are made from recorded data on a spreadsheet.

INRA Le Pin database

A database merging experimental data from three large paddocks of permanent pasture was built, with data from 1992 to 2010 (19 consecutive years). During this period, paddocks were mainly grazed by dairy cows, from early April to November, with a maximum of one silage cut per year. Grazing and feeding management (nitrogen fertilisation level, grazing severity or stocking rate, and cow supplementation strategy) were variable between years according to experimental programs, but strictly similar within year between the three paddocks, enabling comparison of between-paddock pasture utilisation. The grazing system was a simplified rotational grazing system, with an average of ten days residence time per paddock without using electric fences, and a change of paddock being decided from the lactation curve within each paddock (Hoden *et al.*, 1991). The HerbValo tool was used with this database, enabling the between-year and the between-paddock variability of annual and seasonal pasture utilisation, as well as the relationship between pasture utilisation and climate, to be examined over a 19-year period.

Results and discussion

In the 19-year database from Le Pin-au-Haras, the pasture utilisation rate averaged 9.3 ± 1.48 t DM ha^{-1} year $(y)^{-1}$ and ranged from 6.5 to 14.2 t DM ha^{-1} y^{-1} depending on paddock, year and management (Figure 1a). Pasture utilisation rate ranged from 8.8 to 9.6 t DM ha^{-1} y^{-1} between paddocks (average of all years), and from 6.7 to 12.5 t DM ha^{-1} y^{-1} between years (average of all paddocks), showing a larger year effect than a paddock effect. This may be related mainly to the fact that the three paddocks were relatively homogeneous (adjacent permanent pastures of close botanical composition, and deep soils).

Pasture utilisation rate was greatest in spring (late March to end of June), and lowest in summer (July and August) and autumn (September to November), with, on average, 5.3 ± 0.77, 2.0 ± 0.37 and 2.1 ± 0.77 t DM ha^{-1} $season^{-1}$, respectively. The between-year variability of pasture utilisation was thus greater in spring and autumn than in summer in absolute values, but greater in autumn than in spring and summer in relative values (coefficient of variation of 14, 18 and 37% for spring, summer and autumn, respectively). There was no apparent carry-over effect of a high or low pasture utilisation rate in spring on the subsequent pasture utilisation rates in summer or autumn (Figure 1b), showing that seasonal pasture utilisation rates are fairly independent, probably related to specific weather conditions and pasture growth rates. Between years, pasture utilisation rate was positively related to mean temperature during the growing season (+0.8 t DM ha^{-1} y^{-1} per °C) but not to rainfall (infrequent rain deficit in summer in this region).

The feedback from 30 dairy farmers who used the tool in 2016 is positive, but farmer motivation is required to record events all year round (only 5 minutes per rotation per paddock is required). Improvements to the dairy cow version of HerbValo were made in 2017 from the farmer feedback to increase the usability of the method. Ongoing projects aim to develop web applications of the HerbValo method for all herbivore

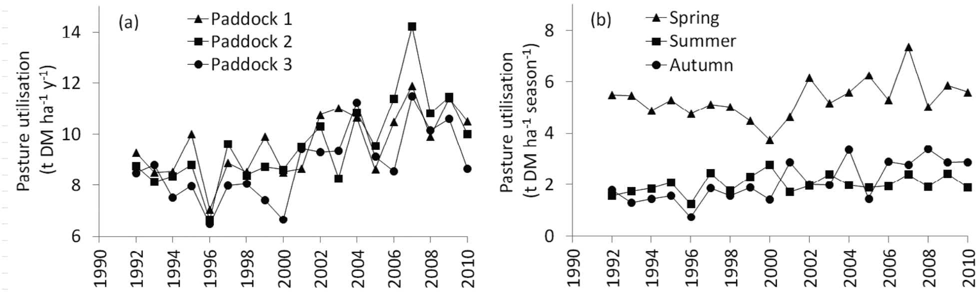

Figure 1. Interannual variation of pasture utilisation by grazing dairy cows: (a) per paddock, with same management, at year level, or (b) per season, on averaged data of three paddocks.

species (bovines, ovines, caprines and equines) to study the relationships between pasture growth and pasture utilisation, and to highlight grazing management practices that can improve pasture utilisation rate through using HerbValo on a large network of farms and paddocks at country level.

Conclusion

The HerbValo method has been collaboratively developed by research and extension services, to calculate simply but accurately pasture utilisation rate at paddock level on farm. Using a large database from an experimental farm clearly showed that HerbValo makes it possible to analyse the between-year, between-paddock or between-management variations in pasture utilisation rate.

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Teagasc/Irish Farmers Journal BETTER Farm Beef Programme

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Abstract

The Teagasc/Irish Farmers Journal BETTER Farm Beef Challenge is a joint industry funded programme sponsored by Dawn Meats, ABP, Kepak and FBD. The programme aims to improve the level of profitability on suckler and beef farms in Ireland. The programme consists of 27 monitor farms located throughout Ireland. All farms involved in the programme are commercial. In return for participating in the programme, farmers receive intensive one to one advice from a dedicated BETTER Farm advisor over a 3 year period. The farmers will work to implement the advice given with a view to increasing output and profitability on the farms to achieve a gross margin of €1,250 ha^{-1}, excluding all EU subsidies. The programme aims to work on a number of challenges with the farmers. Challenges focus on grassland management, soil fertility, labour hours, herd health, breeding, health and safety, green farming, market specs, financial management and mixed grazing. All the information gathered during the programme will be reported on a weekly basis through the Irish Farmers Journal along with using social media such as Facebook, Snapchat and Twitter.

Keywords: beef farms, BETTER Farm, monitor farms, social media

Introduction

The Teagasc/Farmers Journal BETTER (Business, Environment and Technology through Teaching, Extension and Research) farm beef programme was established in 2009. The objective was to improve the productivity and profitability of beef farming in Ireland. To date, the programme has comprised of two phases. The first three-year phase ran from January 2009 until December 2011 with Phase 2 running from 2012 to 2016. The objective of this paper is to document changes in financial performance, grassland management, breeding and herd health on the participating farms over this period. In total, 31 farmers took part for the duration of the programme. The average farm size was 57 hectares with a range of systems operating on farm including suckler to weanling, suckler to store, suckler to finishing and trading systems where all stock are purchased at store stage and finished on farm.

BETTER Farm Financial Management

Farmers participating in the Teagasc/Irish Farmers Journal BETTER Farm Programme were required to carry out financial analysis on the farms in each year of the programme. Each farm completed a Teagasc EProfit Monitor annually. The financial target for all farms was to achieve a gross margin of €1000 per hectare. This margin excludes all fixed costs on the farm and all subsidies associated with the farm. The results of the financial analysis showed a wide variation in the levels of profitability achievable from various cattle rearing and finishing systems. Farms using a suckler to weanling production system typically had lower levels of output on farm which transpired to lower levels of profitability. Farms using a suckler to finishing system finished with male progeny as bulls typically had higher levels of farm live weight output which transpired to higher levels of profitability. These finishing farms typically ran higher whole farm stocking rates and achieved a higher live weight per livestock unit.

Financial summary

Table 1 outlines how gross margins have improved since the beginning of Phase 1 of the BETTER Farm programme. For the phase 2 participants, average gross margin has increased from €675 ha^{-1} in 2012 to €1,029 ha^{-1} in 2015. At a production systems level, gross margins were: €715 ha^{-1} for weanling producers (compared to €363 ha^{-1} nationally); €785 ha^{-1} for store traders (compared to €572 ha^{-1} nationally); and €1,241 ha^{-1} for suckler to finishing (compared to €532 ha^{-1} nationally). Within the finishing systems, farms incorporating under 16- month bulls performed best at a gross margin of €1,464 ha^{-1} in 2015, followed by suckler to under 20 month bulls at €1,220 ha^{-1}. Suckler to steer finishing systems achieved a gross margin of €1,083 ha^{-1}.

BETTER Farm breeding

Maximising output on suckler farms starts with maximising output per cow. The goal on every farm is to produce a live calf every year, of good quality, achieving a good live weight for age. Over the course of the programme, the target was to achieve 0.95 calves per cow per year. The participants averaged 0.92 calves per cow in 2015, just under the target, while the national average stands at 0.82 calves per cow per year.

A critical component of producing a calf per cow annually is to have an inter-calving interval of 365 days. In 2015, the national average for the suckler herd in Ireland was 407 days, while the average across the BETTER farm programme was 378 days. The average calving interval in 2015 varies greatly across the BETTER farms with a range of 412 to 355 days. In comparison, in 2012 the range was from 441 to 342 days.

To achieve high levels of output and production efficiency, minimal levels of calf mortality are required. The targets are to have calf mortality below 2.5% at birth and below 5% at 28 days. In 2015, the BETTER farm participants had 2% calf mortality at birth and 4.5% calf mortality at 28 days. In comparison, the national average herd was much higher with 4.7% mortality at birth and 6% mortality at 28 days.

The average number of calvings per cow in the programme was 4.3, which is on par with the national average. This figure varied from 3.9 to 5.5 between the farms in 2015. In 2012, the variation was greater from 2.6 to 6.2 between the farms.

BETTER Farm grassland management

Planning for early spring grass starts the previous autumn by closing up pastures in rotation from mid-October using the '60:40 autumn planner'. Similarly, the '40:60 spring rotation planner' is used for the first rotation to ensure that farmers have sufficient grass covers on the farm for the second rotation. Using a rotational grazing system maintains grass quality throughout the year and is an effective method of growing more grass. However, it is essential that the farm is walked on a weekly basis to measure grass growth and to assess the supply of grass. This is one of the most important aspects of grassland management as it allows the farmer to budget grass to maintain enough grazing days ahead, good utilisation and ultimately, maintain a highly digestible leafy sward. Grass budgeting using the 'grass wedge' will identify if there is a shortage or surplus of grass coming and will allow the farmer to react in advance.

Table 1. Average gross margin (€ ha^{-1}) for farms on the BETTER farm beef programme.

	2009	2010	2011	2012	2013	2014	2015
Gross margin (€ ha^{-1})	286	405	553	675	579	837	1,029

Weekly grass measurements are recorded by farmers to closely monitor grass growth and thus, aid effective grassland management decision-making. Although 2014 was an exceptional year for grass production, on average, grass growth was only 5% lower across the BETTER Farms in 2015 compared to 2014. The south-west and south-east regions had the largest decrease in growth and this was mainly due to slower growth rates in spring of 2015 and the dry weather in June, which reduced growth on many farms. Farms in the north-east and north-west experienced similar grass growth in 2015 compared to 2014. On average, the BETTER farmers grew almost 10.5 t DM ha^{-1} in 2015 with a regional breakdown as follows: south-west, 12.5 t DM ha^{-1}; north-east, 10.0 t DM ha^{-1}, south-east 9.7 t DM ha^{-1}; north-west 9.4 t DM ha^{-1}.

BETTER Farm herd health

During both phase 1 and phase 2 of the BETTER Farm programme, herd health has remained a key focus area due to its important impact on animal reproductive and live weight performance.

In phase 1, BVD eradication was targeted on farms and from the 14 herds that used the 'ear notch' test to detect PIs, 32 PI animals were found, with 10 PI animals in the most severely affected herd. Involvement from the local veterinary practitioner, the Department of Agriculture and the Marine Regional Veterinary Laboratories and Animal Health Ireland was essential in addressing this issue on programme farms. During Phase 2, the programme has focused on areas such as liver and rumen fluke. Farmers in the programme carried out faecal sampling at housing. Tests were carried out on the samples for both rumen fluke and liver fluke and winter dosing plans were based on these results. Stock showing negative or low infestations of fluke were left untreated and tested again subsequently to determine if any infestation had built up in the interim, while stock showing positive or highly positive results were treated with a suitable product.

Conclusion

The gross margin on farms participating in the BETTER Farm Beef Programme increased by 53% (equivalent to €18,655 per farm) over the course of the programme. This was as a result of a number of factors. Stocking rates increased from 1.98 LU ha^{-1} to 2.27 LU ha^{-1} from 2012 to 2015. Gross output increased by 22% and variable costs increased by 8% over the course of the programme. Grass growth rates on programme farms averaged 10.3 t DM ha^{-1} in 2015 compared to the national average of less than 6 t DM ha^{-1} on beef farms. BETTER Farms also achieved a 382 days calving interval compared with the current national average of 407 days. Herd health improvements contributed to higher levels of output, reduced vet bills and lower labour requirements.

Grassland-based beef production: a case study on the economic impact and ecosystem services in a Limousin cattle farm

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Abstract

This case study assessed the economic impact of grassland-based beef production and associated ecosystem services in a commercial Limousin cattle farm. It aimed to determine (1) the technical and economic performances of different fodder crops including permanent and temporary grasslands, (2) how grazed grass and self-produced fodders are utilised by young bulls and heifers, and (3) associated ecosystem services including carbon fixation of permanent grassland soils and beef meat quality produced from grass. Data were collected from 2013 to 2015. Dry matter yield, nutritional value and cost price were determined for each fodder crop. Animals were weighed every three weeks. In 2015, meat samples from seven bulls finished on pasture were analysed for fatty acids composition. Average daily gains ranged from 1.29 kg day^{-1} in 2015 to 1.35 in 2014 for young bulls grown on grazed grass without supplementation. Grassland soil carbon content linearly increased with grassland age. The meat polyunsaturated fatty acids content increased with grazing duration. In conclusion, this study showed that grassland allows an increase in both the economic and environmental sustainability of beef production systems but also offers nutritional health benefits to the consumer.

Keywords: grassland, grazing, meat production, feed autonomy, carbon fixation, PUFA

Introduction

During the last decades, an increasing number of farmers have actively developed the feed autonomy of their farms (Lucas *et al.*, 2016). This relies, in particular, on high grassland production, including grazed pastures and other fodder. The economic impact of a grassland-based beef production and associated ecosystem services (ES) were assessed in a commercial Limousin cattle farm. Three questions were addressed based on the challenges of the farm:

1. To determine the technical and economic performances of on-farm produced fodders.
2. To explore how cattle utilise the on-farm produced fodders. Two cases were studied: (1) growing and finishing young bulls on grazed grass during the grazing season, and (2) growing young bulls and heifers with on-farm produced rations during winter.
3. To investigate ES associated with a grassland-based beef production. Two aspects were considered: (2) carbon fixation in permanent grassland soils, and (2) beef meat quality produced on grass in terms of fatty acid composition.

Materials and methods

This case study was conducted from 2013 to 2015 in the Ferme Saint-Michel, located in the loamy region of Belgium, province of Hainaut (Faux, 2016). In 2015, the farm was in conversion to organic agriculture. The dry matter (DM) yield and nutritional value (Van Es, 1975; Tamminga *et al.*, 1994) of each fodder crop were determined: maize (*Zea mays* L.) (2013), immature rye (*Secale cereale* L.)-Italian ryegrass (*Lolium multiflorum* Lam.) mixture (2014), immature cereals-protein crops mixture (2015), alfalfa (*Medicago sativa* L.)-dactyl (*Dactylis glomerata* L.) mixture (2013-14-15), permanent grasslands (2013-14), and protein pea (*Pisum sativum* L.) (2013-14-15). Cost price of each crop was computed based on operational and structural costs divided by crop DM production. The economic margin was obtained by subtracting the total costs from the economic value, estimated based on the crop nutritional value and the relationship between market price and nutritional value of feeds taken as references.

The performances of young bulls grown on grazed grass before being finished indoors in 2013 or on grazed grass with supplementation (2014-15), were recorded. The winter growth of young bulls and heifers was monitored. Animals were weighed every three weeks. The cost price and level of feed autonomy of each ration was computed.

Ecosystem services were assessed as follows: the soil carbon (C) content was determined in nine grassland plots of age ranging from 1 to 29 years. The impact of grazed grass consumption on meat quality in terms of fatty acid composition was assessed in 2015 by analysing meat samples from seven bulls slaughtered after distinct grazing durations.

Results and discussion

The highest DM yields were obtained with maize, the largest economic margin was achieved with the grazed pasture and alfalfa-dactylis mixture. This was explained by the high crude protein content of these fodders and the high protein economic value. It emphasized potential profit that can be achieved by producing protein-rich fodders.

Average daily gains (ADG), ranging from 1.29 to 1.35 kg day^{-1}, were obtained with young bulls grown on grazed grass during spring without supplementation. Such ADG were associated with low ration cost prices (Table 1, Case study 1A).

Table 1. Animal performances, cost price and feed autonomy levels obtained with rations dedicated to young Limousin cattle during the grazing season (Case study - 1) and during winter (Case study - 2).

Year	Trial period	No. of animals	Ration[1]	Age at start (month)	ADG[2] kg day^{-1}	Ration cost € kg^{-1} DM	Ration cost € day^{-1}	Ration cost € kg^{-1} weight gain	Feed autonomy level (%)
Case study 1									
A. Growing young bulls at pasture									
2013	30/04 - 6/07	8	Grazed grass	13	1.32	0.11	1.05	0.79	100
2014	26/04-30/08	7		11,8	1.35	0.11	1.05	0.77	100
2015	2/05-12/09	8		13.5	1.29	0.1	0.95	0.74	100
B. Finishing young bulls indoors									
2013	3/08-20/10	3	SBpulp+Trit+PP+CC	17.3	1.53	0.25	2.49	1.63	91 to 33
C. Finishing young bulls at pasture									
2014	1/06-30/09	4	Grazed grass+SBpulp+Trit	16.3	1.62	0.14	1.44	0.89	100 to 76
2015	1/06-31/08	3	Grazed grass+Trit+orgCC	17	1.45	0.19	1.93	1.33	77
Case study 2									
A. Winter rations for young bulls									
2013	4/10-26/12	8	Maize+Alf-Dact+ Trit+PP+CC	15	1.39	0.14	1.46	1.05	93
2014	1/01-11/03	8	Maize+SBpulp+Trit+CC	9.1	1.25	0.16	1.35	1.08	84 to 63
2015	20/01-8/04	11	Rye-IRG+PP+Trit+orgCC	10.8	1.29	0.18	1.5	1.16	94
2016	29/01-29/03	8	ICP+Trit+Barl+orgCC	10.9	1.38	0.21	1.78	1.29	96
B. Winter rations for 1-year old heifers									
2014	1/01-11/03	5	Maize+SBpulp+Alf-Dact	8.6	0.84	0.11	0.73	0.87	100 to 86
2016	29/01-29/03	7	ICP+Alf-Dact+Cereals	10.5	1.08	0.12	0.81	0.75	100
C. Winter rations for 2-years old heifers									
2016	29/01-29/03	8	ICP+Alf-Dact	21.9	0.82	0.09	0.85	1.04	100

[1] Alf-Dact = alfalfa-dactyl mixture, Barl = winter barley, CC = concentrate, orgCC = organic concentrate, ICP = immature cereal-legume mixture, PP = protein pea, Rye-IRG = rye-italian ryegrass mixture, SBpulp = sugarbeet pressed pulp, Trit = triticale. The composition of rations is fully described in Faux (2016).
[2] ADG stands for average daily gain.

Finishing young bulls on grazed grass with supplementation offered (Case study 1C) rather than indoors (Case study 1B), reduced the ration cost price while providing comparable ADG. A live weight of 703 kg and a carcass weight of 471 kg were obtained at 19 months, slaughtering age, with bulls finished at pasture on average over 2014 and 2015. For winter rations, the inclusion of a protein-rich fodder like the alfalfa-dactylis mixture provided satisfactory ADG and resulted in relatively low ration cost prices (Case study 2).

In terms of ES, the soil C content linearly increased with grassland age (Figure 1.1). This could be explained by the accumulation of root biomass and raises the question of the potential of long-term C sequestration in grassland soils (Acharya *et al.*, 2012). An increased content in polyunsaturated fatty acids (PUFAs) in beef meat with grazing duration was observed (Figure 1.2), which suggests that the feeding strategy (i.e. growing bulls on grass as much as possible) positively affects meat quality and is in agreement with Duru *et al.* (2017).

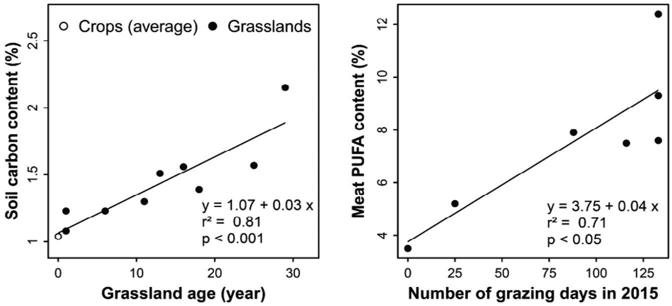

Figure 1. Ecosystem services associated with grass-based beef production. (1) Soil C content in grasslands of distinct ages; (2) PUFA content in meat from Limousin bulls slaughtered after distinct grazing durations.

Conclusion

This study analysed the economic impact and associated ES of a beef cattle production system based on grazed grass and self-produced fodder. Results suggest that using grassland effectively increases both the economic and environmental sustainability of beef production systems and offers the consumer a product with nutritional benefits.

Acknowledgements

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Soil compaction: an issue for German grassland farmers?

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Abstract

In areas with increasing farm sizes, soil compaction is a relevant issue due to the increasing size and weight of agricultural machines. How do farmers perceive soil and soil compaction and how relevant do they view the need to prevent soil compaction? In this paper, we approach these research questions by looking at this topic with a specific focus on grassland. In comparison to other cropping systems, we question if there are differences in how grassland farmers estimate soil compaction and stay informed (e.g. extension service, information channels, etc.). The aim is to improve the knowledge transfer on soil compaction/ technical soil protection. For our analysis, we combine a media analysis and an online survey. We found no difference between farmers with and without grassland in the perception of soil compaction but differences in extension services and information sources used.

Keywords: soil compaction, technical soil protection, knowledge transfer, Germany

Introduction

Preserving a productive soil structure is pivotal for the successful long term management of agricultural land. Especially in areas with increasing farm sizes, soil compaction is a relevant issue due to the increasing size and weight of agricultural machines. Soil compaction can cause long-term irreversible damage to soil functions and negatively impact productivity (Brunotte *et al.*, 2014). For the successful implementation of soil protection measures, knowledge of the farmers, attitudes and perspectives is essential. In this paper, we focus on the perception of grassland farmers to soil compaction and their perceived need to take action. Our working hypothesis is that the grassland sward provides better soil protection and reduces the risk of soil compaction in comparison to arable land. Starting from this assumption, we formulate the following theses: (A) the type of land (grassland or other) influences the perception of soil compaction; and (B) that current channels used to spread information on technical soil protection are not relevant for grassland farmers.

Materials and methods

For our research, we combined a media analysis with an online survey. We analysed the five leading agricultural journals in Germany in order to determine how often soil compaction or avoiding soil compaction was mentioned as a topic in articles of these journals. The media analysis included more than 4,000 articles between 2013 and 2015. We coded the findings and categorised them with respect to management processes and the type of land concerned (grassland and arable land). In addition, we conducted an online survey of German farmers in February and March 2017. The survey focused on farmers' perception of soil compaction and the measures undertaken to avoid this problem. We defined perception after Simon (2001), as decision-making by farmers. Additionally, we asked for soil and climate characteristics, relevance of different information channels on soil compaction and socioeconomic aspects (e. g. farm characteristics, education level). We compared the results on information channels with the results of the media analysis. In total, we received 284 responses; thereof, 164 responses were reasonably complete and were considered in the further analysis (72 with grassland and 92 without grassland).

Results and discussion

More than half of the surveyed German farmers mentioned soil compaction as quite or very important regardless of the presence or absence of grassland. In addition, the way they determined their rating was similar: (1) soil physical effects, (2) plant physical effects and (3) economic effects in both groups. Consequently, we have to reject our first thesis.

We analyse the use of advisory services for technical soil protection and the use of different information channels to answer our second thesis. The farmers without grassland used extension services more frequently with regard to soil compaction compared to grassland farmers (Figure 1). Further grassland farmers most frequently used extension services of professional associations whereas farmers without grassland chose the services of the Chamber of Agriculture, private or official consultancies or even other providers (Figure 2).

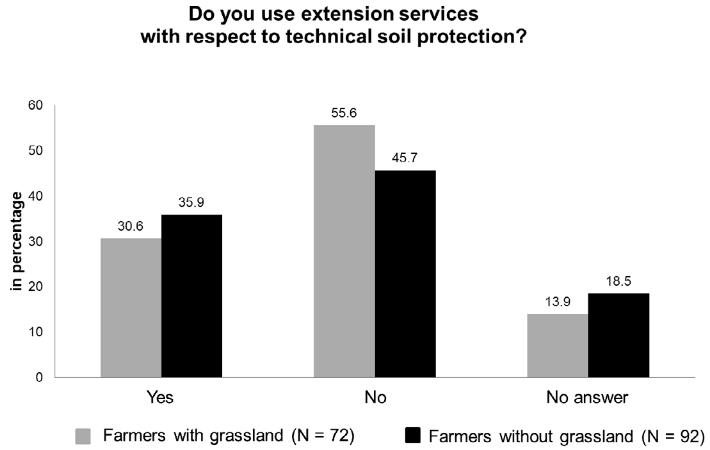

Figure 1. Use of extension service with regard to technical soil protection.

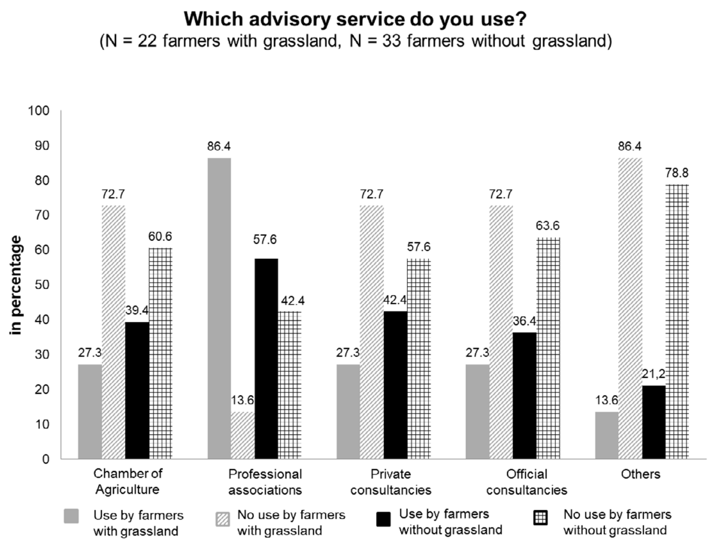

Figure 2. Overview of the relevance of different advisory services for farmers.

Farmers expected reliable information on methods/techniques to limit soil compaction by scientific institutions and agricultural journals (60% or more). In addition, 60% of farmers without grassland expected information from the Chamber of Agriculture compared with only around 40% of grassland farmers. Both groups also mentioned professional colleagues (40%). We matched these results with the results of the media analysis. The topic was barely addressed by the journals and the articles almost exclusively addressed soil compaction in the context of arable farming. Our review of information materials revealed that federal state-run research institutions and the Chambers of Agriculture frequently provided information on the topic at different levels of quality and user-friendliness. Furthermore, our findings also showed that more than half of the surveyed farmers in general would like more field days and information events with less than one fifth mentioning other learning formats.

Due to the applied survey method, this research is not regionally representative for Germany as Lower Saxony is overrepresented within the responses. Unfortunately, representative data on soil compaction are lacking. Our data provide a first trend statement on the farmers' awareness on soil compaction and the main information channels used. The results provide some hints and information on how knowledge transfer should be redesigned and implemented (e.g. more user-friendliness, more practicability). In particular, new digital learning methods should be considered. In our ongoing analysis, we are looking at implemented measures with regard to technical soil protection. This allows us to identify and target specific information/measures to farmers within an improved knowledge transfer service.

Conclusion

Our research shows that soil compaction is equally important for farmers with grassland or without grassland. However, there are differences in how these groups gather information and use extension services. In the future, these differences should be reflected in concepts of knowledge transfer especially for the transfer of research findings into practice.

Acknowledgements

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Adoption of grass measurement and management technologies in dairy discussion groups

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Abstract

Profitability on Irish dairy farms is closely associated with grass utilisation per hectare. This can be enhanced by the use of internet based grassland management support tools such as PastureBase Ireland (PBI). Three levels of support available for adoption of this technology within dairy discussion groups (DGs) were examined. Purposive sampling was used and a quasi-experiment was established. A mixed methods approach involving questionnaires, interviews and focus groups with farmers, in addition to interviews with group facilitators, was used. IBM SPSS Statistics, Version 24 was used for questionnaire analysis and NVivo 11 for qualitative analysis. Study farmers believe in the benefits of grass measuring and management technologies. The results of this analysis indicate that adequate support for adoption can come from a grass focused DG without requiring individual support.

Keywords: dairy, grassland management, adoption, PastureBase Ireland, discussion groups

Introduction

Grass based systems of milk production offer a competitive advantage to the Irish dairy industry (Hurtado-Uria *et al.,* 2013). Grass is the cheapest feed available and Irish farms have the potential to produce 12 to 16 t grass DM ha^{-1} (O'Donovan *et al.,* 2011). PBI is an internet-based grassland management decision support tool and national database for commercial grassland farms developed by Teagasc and in operation since 2013. Currently, approximately 3,000 farmers are using PBI. Dairy farmers recording regular measurements on PBI have grown 12 to 14 t grass DM ha^{-1} $annum^{-1}$ from 2013 to 2016 (O'Leary *et al.,* 2017). To achieve optimum levels of grass utilisation, more widespread adoption of best-practice grassland management is needed (O'Donovan *et al.,* 2011). However, adoption is low among Irish dairy farmers. Newman (2016) found that 14% of dairy farmers were completing a grass cover on a grass budgeting programme in a survey of 99 farmers in the south east in 2015. A survey conducted on a sample proportionally representative of all dairy farmers in Ireland, found grass measuring and budgeting had been adopted by an average of 18% of respondents (Creighton *et al.,* 2011). Therefore, the study objective is to examine the level of adoption of grass measuring and internet based grassland management support tools among dairy farmers in DGs with different levels of extension support available.

Materials and methods

This study was carried out in the south east of Ireland in 2017. A quasi-experiment was set up with three levels of extension support available to Teagasc dairy farmer clients in DGs. The three intervention categories of support were: Intensive (I); Semi-intensive (SI); and Extensive (E), summarised in Table 1. A questionnaire addressing levels of measuring and budgeting, support for adoption, farm systems and demographics was administered to farmers at DG meetings in April and May 2017 (n = 67). Analysis was carried out using IBM SPSS Statistics Version 24. Focus groups to provide complementary information to questionnaire results were run in August and September 2017 for each study DG. Four semi-structured interviews were carried out with facilitators of the study groups. Nine semi-structured interviews were carried out with selected group participants based on their level of adoption so that farmers with different levels of adoption from each intervention category were interviewed. These interviews were carried out during October and November of 2017 based on the theory of planned behaviour (Ajzan, 1985).

Table 1. Extension methods applied to the three categories of intervention in dairy DGs.

Intervention category	n	Extension methods applied
Intensive*	17	grass focused DG meetings each month
		one to one support available to farmers
Semi-intensive‡	14	grass focused DG meetings each month
Extensive§	44	general dairy DG meetings each month
		grass discussed along with other topics including breeding, financial management, labour, health and safety.

* Established in January 2017 and in their 1st year as a group during this study.

‡ Established in January 2016 and in their 2nd year as a group during this study.

§ Members of three Knowledge Transfer Programme DGs, mode band for time in a DG was 5 - 6 years (33%).

Results and discussion

All participants in I and SI categories used PBI. When recorded, grass measurements by SI in 2016 (Year1) were compared to I in 2017 (Year1), farmers in I recorded 66% more measurements than those in SI in 2016. The number of recorded measurements ranged from 1 to 48. While the average number of measurements in the E category was two, the 27% of farmers in this category who used PBI averaged eight measurements in 2017 (Table 2).

All farmers in this study believe that grass measuring and PBI are useful. The majority in all categories believe grass measuring is easy to do (Table 3).To adopt new technologies, farmers must believe the potential benefits are worth time and effort that could be spent elsewhere. The technology must be seen as useful and easy to use (Davis, 1989).

Equally, a majority in all categories also believe PBI was easy to use, although this was highest (92%) in category I, the only category in which all participants believed they were getting the necessary support. Participants in the SI category observed, '*It's easy put the measurements in, but it's not easy to know what to do with them*'. They have moved from input of a grass cover to other aspects of PBI, including the feed budget and are *'finding it hard to learn'*. As a result, 36% felt that PBI is not easy to use. Farmers in I had one to one support available to them and 54% availed of this facility. Therefore, higher adoption was seen

Table 2. Levels of adoption of PBI by extension method.

Intervention category	% who used PBI	% recording more than 10 grass measurements during 2017	Average number of grass measurements recorded in 2017
Intensive	100%	35	12
Semi-intensive	100%	79	18
Extensive	25%	11	2

Table 3. Key findings from questionnaire administered to farmers.

Intervention category	% who believe grass measuring is easy to do	% who believe PBI was easy to use	% who believe adequate support could come from a DG	% who believe they were getting the necessary support
Intensive	100%	92%	69%	100%
Semi-intensive	93%	64%	62%	92%
Extensive	87%	62%	55%	68%

with mixed methods. Recorded grass measurements in SI in 2017 are 44% higher than in 2016 (average of eight measurements recorded). Adoption in SI is increasing over time. When interviewed, all three farmers in SI associated grass measuring and PBI use with their DG. This was also the case for the farmer with the highest number of grass measurements recorded in the I category, who saw grass measuring and using PBI as '*the most important job…every week… that makes me the most money*'. Low confidence with computer skills are a major barrier for some farmers '*You have to turn on the computer… and that's not on with me*'. Increased adoption will be seen when other elements of the farmers' environment make it easier to follow through on decisions (Garforth *et al.,* 2004). It was suggested by farmers in all five focus groups that a PBI mobile application would be of benefit *'I've done covers (measurements) that I have never put onto the computer, an app would help'.* This would reduce time and computer skills barriers for some farmers. It will not increase adoption for some farmers in the E category who are '*happy enough with what we are doing with that end of things (grass)*'. They do not see grass measuring as a priority. A farmer in category I availed of one to one support and still had little confidence in relation to computer skills, yet he felt his '(grassland) *management has improved*' as a result of being in the group. Understanding technical terms such as average farm cover (AFC) is a barrier for some '*AFC there 1000…..but what does that mean?*' However, SI category participants felt this improves over time in a DG, '*It's like learning a new language*'.

Conclusion

Farmers in DGs believe in the benefits of grass measuring and the use of internet based grassland management tools. The main barriers to adoption are computer skills, time and understanding technical terms. Adequate support for adoption can come from a grass focused DG; individual support is not always necessary. Computer training to improve skills and understanding is needed by some. A mobile application for PBI would reduce computer and time barriers.

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Analysis of innovation brokering systems related to grasslands across Europe

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Abstract

Innovation brokering system is an organisational structure of persons or institutions that, from a relatively impartial third-party position, purposefully catalyse innovation through bringing together actors and facilitating their interaction on international, national or regional levels. The aim of this paper is to analyse innovation brokering systems (IBS) across Europe that are, or have the potential to be, used in grassland farming. Eight European countries within the Horizon2020 project Inno4Grass were involved in the analysis: Belgium (BE), France (FR), Germany (DE), Ireland (IE), Italy (IT), Poland (PL), Sweden (SE) and the Netherlands (NL). To collect information about IBS related to grasslands in these countries, a questionnaire was developed on characteristics of the different brokering systems and their barriers and benefits. The collected data allowed for an inventory and evaluation of existing structures fostering IBS using descriptive analysis of quantitative data. We concluded that IBS should be an important part of building a European innovation space for grassland-based farming.

Keywords: brokering, grassland, innovation, knowledge transfer, stakeholder

Introduction

In the innovation brokering systems (IBS), a specialised type of innovation intermediary called 'innovation broker' plays the crucial role (Klerkx and Leeuwis, 2009). He or she pursues a brokering role on innovation as its core function and does this from a more neutral and impartial 'honest broker' position (Klerkx *et al.*, 2009). This principle is important in all fields of the food economy, including for grassland-based systems. An innovation broker is focused neither on the organisation nor the implementation of innovations, but on enabling other organisations to innovate (Winch and Courtney, 2007). They are thus mainly 'facilitators of innovation' who do not contribute with substantive knowledge or technology, or make a strong policy driven contribution, but principally enhance the interaction between those actors. In grassland management, IBS can play a key role in getting worthwhile projects off the ground by bringing people together within region, country and the whole EU.

The aim of this paper is to analyse the IBS across Europe that are, or have the potential to be, used in grassland farming, to better understand how IBS can be a lever to better disseminate innovative grassland practices and systems and/or to take an innovation to the market.

Materials and methods

Eight European countries within the Horizon 2020 project Inno4Grass (www.inno4grass.eu) were involved in the analysis: Belgium (BE), France (FR), Germany (DE), Ireland (IE), Italy (IT), Poland (PL), Sweden (SE) and the Netherlands (NL). To collect information about IBS related to grasslands in these countries, a questionnaire was developed on characteristics of the different brokering systems and their barriers and benefits. Sixteen experts representing science and practise institutions were asked for their opinion on type and development phase of IBS, sources, beneficiaries, supporters, dissemination forms and founding of innovations related to grasslands, etc. The questionnaire was composed of 12 open-ended as well as close-ended questions. To acquire quantitative data in some aspects, multiple choice questions were also used. The questionnaire responses were transferred to a spreadsheet and analysed using descriptive analysis of quantitative data.

Results and discussion

Based on information from questionnaires, in most of the analysed countries, the IBS was already established. Only some regions in Italy are in preparation (e.g. Sardinia). Some specific innovation brokers (called facilitator agents) are foreseen in the regional development plans and/or just started in the framework of operational groups. In BE (Wallonia) and FR, the IBS are exclusively dedicated to grassland-based farming in the form of public non-profit organisations, like Fourrages Mieux ASBL and RMT Prairies Demain, respectively. In EU countries, the IBS related to grassland is mostly (73.3% of all responses) not restricted to grasslands alone, but broadly organised in agriculture and as part of AKIS – Agricultural Knowledge and Information System – which links people and organisations to promote mutual learning, to generate, share and utilise agriculture-related technology, knowledge and information (Knierim and Prager, 2015).

Universities and research institutes play the most important role as sources of innovations related to grasslands across Europe (Figure 1). It is worth noting that industry, advisory services and farmers themselves provide new ideas in grassland-based farming. The results of surveys (35.1% of all responses) show that farmers are the main beneficiaries of innovations related to grasslands (Figure 2). They are followed by the advisors, industry, local governments and society. Implementation of grassland innovations are supported mainly by advisory services, universities and research institutions and industry (Figure 3). There are many dissemination forms of innovations related to grassland, especially media, conferences and seminars, meet-ups, dedicated programs and direct implementations on farms (Figure 4).

The analysis revealed that the grassland IBS is characterised by a mix of public and private funding. Both public organisations and private enterprises provide advisory services and agricultural education may have mixed financing or are completely private. According to the responses, the impact of innovations related to grassland is mainly measured using specific metrics and thresholds in terms of economic (45.5%), followed by environmental impact (27.3%), social issues or is not measured (each 13.6%).

Grassland innovations often need a trans-disciplinary approach. This means that support is needed by several competences. The brokering system provides increased possibilities for funding innovative ideas, since heterogeneous innovation groups are supported. The agricultural European Innovation Partnership (EIP-AGRI) fits well in the grassland context.

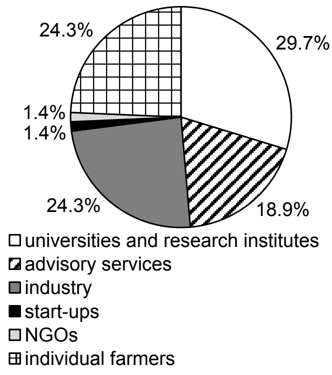

Figure 1. Sources of innovations.

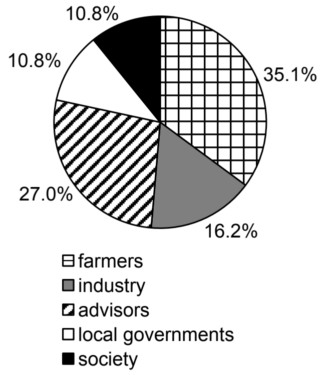

Figure 2. Beneficiaries of innovations.

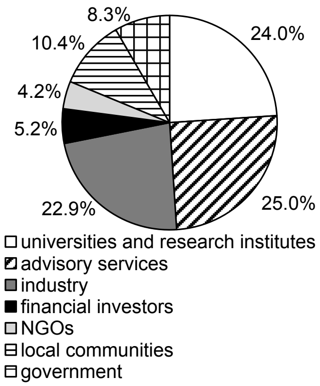

Figure 3. Supporters of innovation implementation.

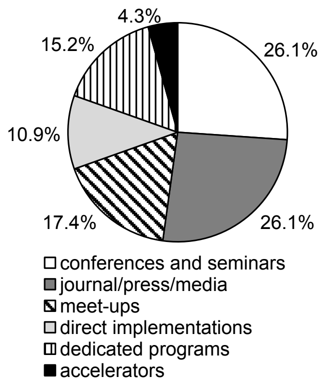

Figure 4. Dissemination forms of innovations.

Conclusion

The currently available IBS related to grasslands are in different development phases in EU countries. They are valuable and should be an important part of building a European innovation space for grassland-based farming.

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What are the main challenges to improve ewe productivity in Ireland and Europe?

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Abstract

A survey was undertaken as part of SheepNet, an EU network, in six main European sheep producing countries, and Turkey, to identify the main challenges to improve ewe productivity. Stakeholders were asked to identify the main challenges to achieving a high pregnancy rate and pregnancy success, and low lamb mortality. There were 794 respondents, 106 of which were from Ireland. While respondents from Ireland and Europe identified the same issues/challenges that enhance pregnancy rate and pregnancy success, and reduce lamb mortality, they ranked them differently in order of importance. It is concluded that, whilst the challenges to improving sheep productivity are similar across Europe, the order of importance may differ in different countries. The solutions to these challenges may also differ between rearing systems and regions. SheepNet is well positioned to provide appropriate solutions to improve sheep productivity within region and production system across Europe.

Keywords: survey, Europe, lamb mortality, gestation, nutrition management, reproduction

Introduction

Sheep production is practiced in most European countries, which differ in both climatic and environmental conditions. Systems of sheep production vary from lowland pastures to mountain terrain in temperate climates, to areas of sparse vegetative growth, rugged topography and confinement in Mediterranean and semi-arid regions. Currently, there are 830,000 sheep farms and 85 million animals in Europe (Eurostat, 2013) and 127,000 sheep farms and 85 million animals in Turkey (TUIK 2015). However, since 2000 the number of sheep flocks and producers in the EU has declined by 15 and 50%, respectively. The decline in the sheep industry is attributable to a number of factors including the low levels of ewe productivity. The EU is only 85% self-sufficient in sheep meat and is the largest importer of sheep meat worldwide (FAOSTAT, 2015). An increase in EU ewe productivity by 0.1 lambs reared per ewe joined would increase self-sufficiency in sheep meat to 92%. Ewe productivity (number of lambs reared per ewe joined) is a combination of reproduction success, embryonic and lamb survival and litter size.

SheepNet is an EU/international Thematic Network (grant agreement No. 727895) on sheep productivity designed to stimulate knowledge exchange between research and stakeholders to widely disseminate best practices and innovations, with the objective of increasing ewe productivity. The objective of this paper is to present results of a survey, undertaken in six EU countries and Turkey, to obtain and assess the opinion of farmers, KT (knowledge transfer) personnel, veterinarians and other stakeholders within the sheep industry to: (a) identify the main challenges and needs to improve pregnancy rate and pregnancy success, and (b) the main management and animal issues to reduce lamb mortality.

Materials and methods

During March and April 2017, the survey was launched and circulated online or by mail to stakeholders involved in sheep production in all SheepNet country partners (Ireland, France, Italy, Romania, Spain, Turkey and the UK). The survey contained 22 questions which were predominantly close-ended; some open-ended questions were also included. A collaborative work task between SheepNet partners agreed the definition of the different rearing systems and identified putative main challenges (for close-ended questions). The survey was delivered in the six SheepNet languages. The questions included were on the profession of the respondent, and for farmers, information on their sheep enterprise. The respondents were asked to rank in order of importance a maximum of five main challenges and needs that enhance pregnancy rate (choice of 16 options) and success (13 options), and the main management (11 options) and animal factors (11 options) involved in achieving low lamb mortality. The data was cleaned and screened for anomalies. A score was assigned to each of the five choices: the first choice (most important) was scored 5 to the fifth choice (least important) scored 1. The final rank of needs was based on the sum of the scores.

Results and discussion

A total of 794 surveys were completed (106 from Ireland). The respondents were classified into three groups, namely Europe (all respondents from France, Italy, Romania, Spain, Turkey, UK) Ireland farmers (86 farmers, 2 farm workers) and Ireland other (8 knowledge exchange staff, 4 researchers, 3 veterinarians). Fifty seven percent of all respondents to the survey were farmers. Of the farmer respondents, 68% were involved in meat production. The main farming system of the respondents was semi-intensive (45%), semi-extensive (28%), shepherded (11%), intensive (10%) an extensive (6%). In Europe and Ireland, lambing occurred indoors on 86 and 84% and ultrasonic pregnancy scanning occurred on 55 and 99% of the farms, respectively.

The main challenges and needs identified, from 16 options, to improve pregnancy rate are presented in Table 1. There was general agreement among the three categories of respondents. The European group also identified ewe lamb and ram management as important issues while the Irish identified ram management, ewe: ram ratio and breeding period of the year as important issues.

The main challenges and needs identified, from 13 options, to improve pregnancy success are presented in Table 2. There was also general agreement among the three categories of respondents on the three main challenges and needs to enhance pregnancy success. Europe and Irish farmers agreed on the fourth and fifth challenges and needs. Ireland-other respondents identified handling facilities and how to assess a gestation nutrition plan as important issues.

Table 1. Ranking of the main challenges and needs to improve pregnancy rate.

	Europe[1]	Ireland - farmer	Ireland - other
Body condition score	2[2]	1	1
Nutrition/grassland management	1	3	2
Flock health status	3	2	3
Ewe lamb management	4		
Breeding period of year			4
Ram management	5	4	
Ewe: ram ratio		5	5

[1] France, Italy, Romania, Spain, Turkey, UK.

[2] Most important to 5 less important.

Table 2. Ranking of the main challenges and needs to improve pregnancy success.

	Europe	Ireland -farmer	Ireland - other
Nutrition/grassland management	1	1	1
Abortion: control and prevention	2	3	2
Pregnancy diagnosis (scanning) – benefits	3	2	2
Mineral nutrition during pregnancy	5	4	
Internal parasite control		5	
How to assess a pregnancy nutrition plan	4		4
Animal handling facilities			5

The main management issues identified, from 11 options, to achieve low lamb mortality are presented in Table 3. All groups identified the same five issues, but ranked them differently in order of importance. The main issue identified by all was advance preparation for lambing. The second major issue for Irish farmers was labour availability, for Europeans it was sheep shed management, and Irish-other it was hygiene.

Table 3. Ranking of the main management issues to reducing lamb mortality.

	Europe	Ireland - farmer	Ireland - other
Advanced preparation for lambing	2	1	3
Sheep shed (ventilation, hygiene, etc.)	1	4	5
Nutrition/grassland management	3	3	1
Labour availability/organisation	5	2	4
Hygiene (e.g. naval disinfection)	4	5	2

The main animal issues identified, from 11 options, to achieve low lamb mortality are presented in Table 4. The three groups of respondents identified the same three major issues but in a different order of importance. The Irish respondents also identified lambing difficulty as a major issue whilst the European group identified lamb health as a major issue.

Table 4. Ranking of the main animal issues to reducing lamb mortality.

	Europe	Ireland - farmer	Ireland - other
Colostrum issues	1	1	2
Lamb vigour at birth	2	2	3
Lamb birth weight	3	3	1
Lamb health	4		
Mis-mothering (ewe-lamb bond)	5		
Litter size		5	
Weak lamb management			3
Lambing difficulties		4	4

Conclusion

There are similar challenges to improving sheep productivity across Europe but the order of importance differs by region. SheepNet is well positioned to provide appropriate solutions to improve sheep productivity within regions and production systems across Europe. As some challenges are region specific, other countries may have previously had these problems and developed practical solutions which they will share. All research of practical and innovative solutions under SheepNet will be driven by the results of this survey.

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What sources are used by stakeholders in Ireland and Europe to obtain information on ewe productivity?

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Abstract

A survey was undertaken to identify the main sources used by stakeholders to obtain information on sheep productivity. The survey was undertaken as part of SheepNet, an EU network, covering six of the main European sheep producing countries (Ireland, UK, France, Italy, Spain and Romania) and Turkey. There were 794 respondents, 106 of which were Irish. The respondents were asked to rank in order of importance thirteen different sources of information on sheep productivity. The Irish respondents were classified into two groups as follows: farmer/farm worker (farmer) and advisor/consultant/scientist/veterinarian (professional). In order of decreasing importance, the five main sources of information used by Irish farmers were discussion groups, farming press, peer to peer, open days and technical advisors/consultants; by Irish professionals were congress/seminars/workshops, scientific articles, technical advisors/consultants, professional learning and farming press; and by European stakeholders were veterinarians, technical advisors/consultants, farming press, peer to peer and professional learning. It is concluded that while there are many different media/sources available to transfer information on ewe productivity to stakeholders, to achieve a successful communication media choice depends on the target audience. Whilst interactive communication and peer to peer were the most important media, the best source of information differed depending on both the background and region of the respondents. Social media and technical sales personnel were considered as poor sources in information by all of the respondents.

Keywords: survey, Europe, Ireland, media, communication

Introduction

Successful transfer of findings and technology from research to stakeholders and their successful adoption by industry is critical to improving efficiency within any farm enterprise. The adoption of technology by producers is influenced by many factors including effective communication. In Northern Ireland, Morrison *et al.* (2009), reported that the most important issues dairy producers consider when deciding on adoption of research findings were 'what are the financial rewards of the change?', 'what is the cost of adopting the change?' and 'what is the labour/time/energy required to change?'

The EU is only 85% self-sufficient in sheep meat and is the largest importer of sheep meat worldwide. An increase in EU ewe productivity by 0.1 lambs reared per ewe joined would increase self-sufficiency in sheep meat to 92%. Ewe productivity (number of lambs reared per ewe joined) is a combination of reproduction success, embryonic and lamb survival and litter size. In some countries within the EU, ewe productivity has changed little in the past 30 years. The low adoption of technologies could be due to similar issues as reported for dairy producers (Morrison *et al.*, 2009) or for other reasons such as being un-aware of the existence of relevant technology.

SheepNet is an EU/international Thematic Network (grant agreement No. 727895) on sheep productivity designed to stimulate knowledge exchange between research and stakeholders to widely disseminate best practices and innovations with the objective of increasing ewe productivity. The objective of this paper is to present results of a survey, undertaken in six EU countries and Turkey, to compare and assess what are the main information sources that stakeholders in Ireland and Europe use to obtain information on sheep productivity.

Materials and methods

During March and April 2017, the survey was launched and circulated online or by mail to stakeholders involved in sheep production in all SheepNet country partners (Ireland, France, Italy, Romania, Spain, Turkey and the UK). The survey was in the six SheepNet languages (English, French, Italian, Spanish, Romanian and Turkish). The questions included were on the profession of the respondent and for farmers, information on their sheep enterprise. The survey contained 22 questions which were predominantly close-ended. One of the questions asked the respondents to *'rank in order of importance the main information sources that you use to get information on ewe productivity'.* The respondents were given 13 different options which they could rank. The data was cleaned and screened for anomalies. A score was assigned to each of the five choices: the first choice (most important) was scored 13 to the thirteenth choice (least important) scored 1. The final rank of the main sources to obtain information was based on the sum of the scores.

Results and discussion

A total of 794 surveys were completed (106 from Ireland). The respondents were classified into three groups, namely Europe (all respondents from France, Italy, Romania, Spain, Turkey, UK), Ireland-farmer (86 farmers, 2 farm workers) and Ireland-other (8 knowledge exchange staff, 4 researchers, 3 veterinarians). Fifty seven percent of all respondents were farmers. Of the farmer respondents, 68% were involved in meat production. The main farming system of the respondents was semi intensive (45%), semi extensive (28%), shepherded (11%), intensive (10%) an extensive (6%). In Europe and Ireland, lambing occurred indoors on 86 and 84%, and ultrasonic pregnancy scanning occurred on 55 and 99% of the farms, respectively.

The main sources to obtain information on ewe productivity are presented in Table 1. Each group of respondents identified different main sources of information for ewe productivity. Whilst Ireland-farmers identified discussion groups as the most important source of information, Ireland-other and Europe ranked it as relatively unimportant (ranked 8th and 10th, respectively). Meanwhile, Europe identified veterinarians as the most important source of information whilst Irish respondents rank them lower (ranked 6th and 9th by Ireland-farmer and Ireland-other, respectively). Whilst Ireland-other ranked congress/seminars/workshops as the most important source of information, Europe and Ireland- farmer ranked them as the 6th and 8th most important source, respectively. However, all groups of respondents ranked technical advisors/consultants and farming press as important sources. There was general agreement among the three categories of respondents of the least important sources of information on ewe productivity, namely technical sales personnel and social media.

Table 1. Ranking of the main sources used to obtain information on sheep productivity.

	Europe[1]	Ireland - farmer	Ireland - other
Veterinarians	1	6	9
Technical advisors/consultants	2	5	3
Farming press	3	2	5
Peer to peer (e.g. farmer to farmer)	4	3	11
Professional learning	5	10	4
Congress/seminars/workshops	6	8	1
Scientific articles	7	9	2
Open days on farm	8	4	6
Farming websites	9	7	7
Discussion groups	10	1	8
Social media (e.g. Facebook, YouTube, etc.)	11	11	10
Technical sales personnel	12	13	-
Other	13	12	-

[1] France, Italy, Romania, Spain, Turkey, UK.

[2] 1 = most important to 13 = least important.

Conclusion

There are many different media/sources available to transfer technical/practical information to stakeholders involved in sheep production across Europe but to achieve successful communication, the choice of media to use depends on the target audience. Whilst interactive communication and peer to peer are important media, the best sources of information differed between the three categories of respondents. Social media and technical sales personnel were considered as poor sources in information by all of respondents. However, media type is not the only key element to transfer information to stakeholders, the content and communication format are also important to target the audience.

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Sharing best practice in discussion groups encourages farmers to achieve top results

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Abstract

New information is shared amongst the farmer members of ProAgria discussion groups by applying and analysing research results, participating in study trips, both within Finland and abroad, and testing the functionality of new ideas in practice at farm level. During the year, the groups gather to compare practices and ideas. Each group and their facilitator support the decision making process. In an example group, there are ten dairy farmers that have gathered regularly since 2011. They produce on average 10,469 kg milk cow^{-1} per year and have an average herd size of 83 cows. On average, 6.5 species are being used in the grass mixture. The average silage yield in the area was 5,480 kg DM ha^{-1} before the group started. In 2017, average silage yield for the group had increased 90% to 10,425 kg DM ha^{-1} while the quality has remained the same or improved. This improvement has had a big impact on silage production costs and on the economy of the whole farm. Some topics which the example group have experienced to be particularly important to their development are: the effect of grass establishment on grass density, diverse grass mixtures and the discussion group membership.

Keywords: benchmarking, discussion group, grassland

Introduction

Farmers participating in ProAgria discussion groups have improved their farm performance over time, leading to better farm competitiveness. There has been a significant increase in good outcomes particularly in western Finland. The results of discussion groups in this region have been followed up since 2011, involving 50 to 80 grassland farmers, depending on the year. A typical Finnish discussion group consists of around ten farmers that gather regularly and have common aims. Each group has a responsible and inspiring facilitator. The facilitators are ProAgria advisors who are trained to do their facilitating work. New information is researched amongst the group and then applied and the results analysed. The research involves the ProAgria advisors and farmers participating annually in study trips abroad and at home and testing the functionality of new innovations in practice at farm level. Decision-making is the joint responsibility of the group and its facilitator.

Aims of discussion groups

In the farmers' groups, targets are set together on a group and farm level and everyone is encouraged to progress. Throughout the year the group meets to compare procedures and to generate ideas that can lead to better results. The aim of the discussion groups is to develop the operation of the farm and the entrepreneur. This is done by researching the best farming methods, comparing them to procedures carried out on the home farm and then applying these to improve the business. The aim is to try and find new and innovative procedures in a changing operational environment.

Background of the example group

Here is an example of one discussion group ('example group'). In this group, there are ten dairy farmers that have gathered regularly since 2011. During this time the group has met on average five times per year and visited dozens of grassland farms all over Finland and Europe. Group facilitators have also made several study trips in Europe and Canada, comparing different countries' discussion group working habits and national grassland management systems. They later shared the acquired information within their own discussion groups back in Finland. The example group has regular conclusion periods every two years. This is the moment when results and targets are re-examined. When the group develops over many years, the significance of applying new information acquired outside the group increases.

Results of the example group

The dairy farmers in this example group produce on average 10,469 kg milk cow^{-1} per year with an average herd size of 83 cows. They make three cuts of silage per year. These farms are located in western Finland. Typical problems of this area are droughts in spring and mid-summer. The soil type on most of the farms is heavy clay. The average silage harvest of the example group has increased after the group started in 2011 (Table 1). In 2017, average yield was 10,425 kg DM ha^{-1}.

In the period of six years, the harvested yield has increased within the whole group on average by 4,950 kg DM ha^{-1}. This has a big impact on silage production costs and on the economy of the whole farm. The feeding and preservation quality has remained the same or improved, depending on the year. For example, D-value of silage in 2012 was on average 666 g kg^{-1} DM compared with 670 g kg^{-1} DM in 2016. Crude protein of silage was 137 g kg^{-1} DM in 2012 and 141 g kg^{-1} DM in 2016. Some topics which the example group farmers feel important to their development during 2015 to 2017 were: the effect of grass establishment on grass density, the differences between soil conditions, the use of diverse grass mixtures, well-adjusted fertilisation and better sowing depth, oversowing and the changing experiences within the discussion group. In addition, regular observation of grass growth, together with a grassland adviser and regular analysis of feed quality were also considered important.

In 2017, the group members achieved their biggest silage yields ever, even when the growing season was difficult in Finland. What the group members thought to be particularly important was that they could benefit from increased enthusiasm and support within the discussion group, and that they were observing the fields constantly. The positive changes they have made during these years are now fully in practice. In the case of problems, the farmers share the reasons for the problems very openly and advise each other to avoid it happening to them. They share very openly their analysis of soil and silage testing and feeding systems and milk yields at group meetings and using social media. The total number of silage samples analysed per farm increased by 51% during these years.

Factors improved by the example group

Observing the fields constantly has helped the farmers to make better decisions, especially when deciding when to fertilise and cut silage, how to prevent weeds and finding out the best possible grassland seed mixtures. The ProAgria grassland expert advisor, who facilitates the group, visits the farms without the group on average twice during the growing season. The farmers also walk the fields weekly and check silage quality daily, without the expert and share pictures and views with one another on 'WhatsApp' and 'Facebook-groups' page, for all the grassland discussion groups to see. The importance of the 'WhatsApp'

Table 1. The average silage harvest (kg DM ha^{-1}) of the example group compared to the whole of Finland.

Year	Finland average (kg DM ha^{-1})	Example group (kg DM ha^{-1})
2010	6,440	5,480
2011	7,030	7,620
2012	6,720	7,760
2013	6,270	8,300
2014	6,080	7,800
2015	5,160	9,340
2016	6,900	9,540

group has been increasing in the example group. The group shares information, for example, about the timing of all the fieldwork decisions.

A significant change with the example group has been the adoption of multi-variety grass seed mixtures; in 2011, the typical grass seed mixture used contained on average two varieties, whereas in 2017, the typical grass seed mixture used contained on average 6.5 varieties. The average clover and/or lucerne percentage is 25% in the fodder mixture. The biggest change in their grass seed mixture happened after the group facilitators and the group members took study trips to other countries. Another significant change has been the density of the grassland, which improved by changing the establishment style. In addition, the idea of acceptable density of the grass sward changed during the study trips to other countries. The farmers of the example group used to have 10 to 12 cm spacing and they did not oversow even if winter damage had been very severe. Most of the group members made changes to the seeding technique and preferred broadcast sowing so that the seed covers more of the soil.

Many of the farmers have changed the method used to establish grassland. Most of the farms still seed under barley (*Hordeum vulgare* L.) or oats (*Avena Sativa* L.), as before, but use less cereal seeds and less nitrogen (N). Many of the farmers have changed the method used to establish grassland to a wholecrop silage mixture. They also started oversowing 50% of their grassland fields annually on average. In addition, in 2011, they had four to six years crop rotation and this has now changed to just three to four years. Nutrients were one of the topical issues in all discussion groups in 2017. As silage yields increased, it was important to make sure that fertilisation was balanced. The farms have reduced the amount of N fertiliser they apply by using clovers/lucerne, with up to 60% in these fields. This makes fertilising partly challenging, if the other nutrients are insufficient and need added fertiliser. Most of the farmers have also regularly applied phosphorus (P), potassium (K), Sulphur (S) and selenium (Se) when using chemical fertiliser over the past years. The most common way to analyse nutrients is to order a comprehensive silage analysis and observe the grass and the cows.

Challenges and the future of the example group

The biggest challenge for the example group farms at the moment is magnesium (Mg) and manganese (Mn) deficiency. In addition, lack of Mg together with high levels of K is a problem, which has had a negative influence on the health of the dry cows. Other topical challenges in the example group include finding the perfect time for silage cuts, managing the drought between the first and second cuts and producing enough NDF in silage. The example group is going to continue for the next three years and try to answer these challenges. Their goal is to increase feeding quality and keep achieving 10,000 kg DM ha^{-1} in any conditions.

Temporary grassland – an optimal alternative in crop rotation systems

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Abstract

Sustainable agriculture has been developed as an alternative to conventional or intensive agriculture with the main components: crop rotation and structure, use of optimal doses of chemical and organic fertilisers and minimum soil cultivation. Of these, crop rotation is the most important component of agricultural systems that contribute to meeting these requirements. For this purpose, an experiment was created wherein, a complex mixture of grasses with legumes were introduced to a crop rotation. In the rotation, the crops following the temporary grassland, find the most favorable conditions for growth and development, achieving higher production, both quantitatively and qualitatively. The medium annual yields of potato crops have ranged between 22.2 (2013) and 41.7 t ha^{-1} (2014). For forage turnips, temporary grassland represents the best precursory crop and provides root yields between 51.8 and 72.5 t ha^{-1} under a low annual fertilisation of 50 kg N, 50 kg P and 50 kg K ha^{-1}. The silage maize green mass production ranged between 48.5 (2009, 50 kg N, 50 kg P and 50 kg K ha^{-1}) and 64.5 (2013, 100 kg N, 100 kg P and 100 kg K ha^{-1}) t ha^{-1}, the maximum being obtained from a variant with sown grassland as the previous crop for two previous years. The spring wheat crop had production of 3,508 to 4,370 kg ha^{-1}, on all variants with precursory the temporary grassland in the first year. The average annual DM yield of temporary grassland, in all variants studied, during the experimental period, was 9.75 t ha^{-1}.

Keywords: temporary grassland, crop rotation, sustainable agriculture

Introduction

Conventional farming systems deliver rapid growth crops with short crop rotations, based on increased quantities of fertilisers and pesticides and resulting in negative repercussions for the physic-chemical state of the soil and the environment. To remedy these disadvantages, it is recommended that agricultural production should transition to more sustainable production methods.

The main goals of this type of agriculture are to maintain and improve soil fertility in the long term, and improve environmental protection via enhanced biodiversity conservation, protecting and stimulating the activity of microorganisms, useful flora and fauna, landscape restoration and beauty.

Crop rotation is among the most important components of agricultural systems which can contribute to achieving these requirements.

This paper aims to evaluate the effects of integrated management of agricultural land to achieve high and constant yield and quality over time within crop rotations by practicing sustainable agriculture with minimal inputs.

Materials and methods

The experiments were carried out during the years 2008 to 2014 (inclusive) on an experimental site in Fagaras, a central zone of Romania, on a mixed farm with vegetable crops and livestock.

The soil type of the experimental site was Podzolic, with the soil reaction ranging from weak to moderate acid with values of pH from 5.23 to 6.13. The experimental field consisted of three blocks (15 × 49 m), each of them being composed by five variants (3 × 49 m) with rotation crops. Within each of the 15 variants, four replicates were included.

The crop rotation was established taking into account suitable crops for this area and the farm requirements and was comprised of temporary grassland (TG), potato (PO), spring wheat (SW), forage turnip (FT) and silage maize (SM). For all crops in the rotation, the recommended agricultural works required by their specific cultivation technology was performed. As the experiment started in 2008, a complex mineral fertiliser application including 100 kg N, 100 kg P and 100 kg K ha^{-1} and limestone amendment (3 t ha^{-1}) were initially applied with an additional 50 kg N, 50 kg P and 50 kg K ha^{-1} in each subsequent year, except for 2013 when a rate of 100 kg N, 100 kg P and 100 kg K ha^{-1} was applied. Each year, the production of fodder, potato, spring wheat, forage turnip and silage maize was determined in addition to samples to determine some indicators of feed quality. Some examples of crop sequences from 15 variants studied are presented in Table 1.

Results and discussion

For these experiments, complex mixtures of grasses and legumes has been introduced in crop rotation and their influence on crop yield and soil state have been studied. In this paper, only the impact on crop yields as a result of using the temporary grassland in crop rotation, is presented. The annual average yields for crops in rotation, with temporary grassland as the precursory crop are presented in Table 2.

In the statistical processing, the variant analysis method was used. The experimental results highlight that temporary grassland is a good precursor for potato. In these variants, the yields ranged between 25.6 and 35.1 t DM ha^{-1}. The highest yields of 37.7 and 41.7 t ha^{-1} were obtained in variants where the rotation of temporary grassland was followed by hoeing plants (forage turnip, silage maize) and a uniformity crop (spring wheat), and with levels of fertilisation of 50 kg N, 50 kg P and 50 kg K ha^{-1} applied. The lowest yield of 13.9 t ha^{-1} was obtained in 2012, mainly due to a deficiency of rainfall during the June to September period that was also associated with high summer temperatures and resulting in an excessive drought.

According to the experimental results, the spring wheat crop had production of 3,858 to 4,370 kg ha^{-1}, on all variants with a temporary grassland precursory crop during the 1st year. One of highest yields of 4,312 kg ha^{-1} was obtained in variants of rotation within temporary grassland in the 2nd year followed by a potato crop. The medium annual yields of spring wheat ranged between 2,112 (2012) and 4,370 kg ha^{-1} (2009).

From the experimental data, temporary 1st year and 2nd year grassland gave the best results for forage turnip resulting in root yields between 51.8 and 72.5 t ha^{-1}, and with levels of fertilisation of 50 kg N, 50 kg P and 50 kg K ha^{-1} applied. In comparison with alternative precursory crops, the relatively high

Table 1. Some examples of crop sequences during the study years.[1]

2008	2009	2010	2011	2012	2013	2014
TG	PO	SW	FT	TG	TG	TG
TG	TG	PO	SW	SM	FT	TG
TG	TG	FT	SW	SM	PO	TG
TG	SM	TG	TG	TG	TG	SM
TG	TG	TG	TG	PO	SM	SW

[1] FT = forage turnip; PO = potato; SM = silage maize; SW = spring wheat; TG = temporary grassland.

Table 2. The annual average yields for crops in rotation with the temporary grassland as the precursor plant.

Precursory crop	Fertilisation rate kg ha^{-1}	Potato t ha^{-1}	Spring wheat kg ha^{-1}	Forage turnip t ha^{-1}	Silage maize Dry matter (Green mass) t ha^{-1}
Temporary grassland 1st year	N50P50K50	25.6*- 35.1***	3,858***-4,370***	51.8*	21.31*** (48.5)
Temporary grassland 1st year	N100P100K100	-	3,508***	-	-
Temporary grassland 2nd year	N50P50K50	26.3* - 27.2*	2,112	72.5***	16.45** (53.5)
Temporary grassland 2nd year	N100P100K100	-	-	40.82	25.28*** (64.5)
Temporary grassland 3rd year	N100P100K100	-	2,553*	-	-
Temporary grassland 4th year	N50P50K50	-	-	-	12.84 (55.8)

Potato: DL 5%=3.26 t DL 1%=5.70 t DL 0.1%=9.15 t
Spring wheat: DL 5%=435 kg DL 1%=628 kg DL 0.1%=924 kg
Forage turnip: DL 5%=7.73 t DL 1%=11.70 t DL 0.1%=18.80 t
Silage maize (Dry matter): DL 5%=2.12 t DL 1%=3.04 t DL 0.1%=4.47 t
*-Significantly; **- Distinctly significant; ***- Very significantly

production of roots was also associated with a reduction in the degree of crop weeding from 19 to 8%, when compared with other crop rotations.

The averages of annual root production ranged between 40.1 (2013) and 72.5 (2010) t ha^{-1}. The experimental data shows that silage maize green mass production ranged between 48.5 (2009, 50 kg N, 50 kg P and 50 kg K ha^{-1}) and 64.5 (2013, 100 kg N, 100 kg P and 100 kg K ha^{-1}) t ha^{-1}, the maximum being obtained from variants with sown grassland as the previous crop for two years.

The data obtained during experiments shows the DM yields, both for each year of temporary grassland existence and crop rotation variant. The medium annual yields were of 8.7 t DM ha^{-1} in the 1st year of use, 11.0 t DM ha^{-1} in the 2nd year, 9.4 t DM ha^{-1} in the 3rd year and 9.0 t DM ha^{-1} in the 4th year. The average annual DM yield during the experimental period of 6 years was 9.75 t DM ha^{-1}.

Conclusion

Crop rotation is an important link of agricultural technologies contributing to constant crop production over time. The results indicate that the introduction of temporary grassland in the crop rotation system has provided favorable conditions for other crops in the rotation.

In addition, the degree of weed participation in the spring was influenced by the previous crop with temporary grassland having a positive influence on the degree of weeding required.

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Benefits and limitations of agroforestry livestock systems: stakeholders perception in Galicia

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Abstract

Agroforestry (AF) is the practice of deliberately integrating woody vegetation (trees or shrubs) with crop and/or animal systems to benefit from the resulting ecological and economic interactions. The appropriate application of AF practices is a key avenue to help the European Union to achieve more sustainable methods of food production. However, there is a lack of agroforestry knowledge among end-users. The project AFINET (AgroForestry Innovation NETworks) is a thematic network to foster knowledge exchange between scientists and practitioners on agroforestry. During the initial stage of the project, an assessment of positive (benefits) and negative aspects (limitations) on the implementation of AF systems was conducted among AFINET stakeholders in Galicia (north-west Spain). The reduction of fire risk, the enhancement of biodiversity and the improvement of landscape aesthetics values were perceived as the main benefits of implementing agroforestry by the stakeholders. On the other hand, the possibility of obtaining grants to establish AF systems was perceived as less important. When asked about the limitations, a lack of knowledge and professional advice were identified as the main barriers for the implementation of AF systems in the region, along with the risk of incompatibilities with the common agricultural policy (CAP).

Keywords: multiactor approach, thematic network, actors, innovation

Introduction

Agroforestry (AF) is the practice of deliberately integrating woody vegetation (trees or shrubs) with crop/pastures and/or animal systems to benefit from the resulting ecological and economic interactions. The appropriate application of AF practices is a key aspect to help the European Union to achieve more sustainable methods of food production (Buttould, 2013). However, there is a lack of AF knowledge among end-users as it was identified by the EIP-AGRI Agroforestry Focus Group (EIP-AGRI, 2018). The project AFINET (AgroForestry Innovation NETworks) is a thematic network to foster knowledge exchange between scientists and practitioners on agroforestry which will produce a set of materials including a searchable repository called 'knowledge cloud'. For this purpose, a series of multi-actor meetings will take place during the project period. In the first meeting, main bottlenecks were identified after discussion. The main aim of this paper is to show the main benefits and limitations found by stakeholders after the multi-actor approach meeting.

Materials and methods

The AFINET project is composed of nine Regional Agroforestry Innovation Networks (RAIN) across Europe. Each RAIN has an initial meeting where farmers were asked to discuss and prioritise the main bottlenecks that limit AF use in their specific region. The focus of the RAIN is regional (because Rural Development Programs and agriculture policies are different for each autonomous region of Spain). The RAIN is composed of about 30 participants from different subgroups. Galicia RAIN was composed of researchers, forest owners, representatives from the Galician Climate Office and livestock farmers associated to different traditional livestock breeds of sheep, goats and cattle. The systems focused upon include: grazing systems of cattle and sheep/goat milk and meat production; celtic pigs in the forests and 'commons' with several types of free-range animals (horses, cattle, pigs, etc.) but also very focused on forestry production. The first Spanish RAIN meeting was attended by more than 30 stakeholders (Figure 1) from the various categories of practitioners (mainly farmers), multipliers (farmers and foresters organisations), private partners (tree nurseries and private advisory services), administration and policy makers (Rural Development Plan technicians and from the Galician Innovation Agency) and researchers (from USC and the Galician Office of Climate Change). The meeting was led by an Innovation Broker and recorded. The analysis of the results was carried out by quantifying the number of times that bottlenecks appeared and by summarising the main concepts given by farmers regarding each bottleneck.

Results and discussion

Identified bottlenecks in the Galician RAIN were varied and broad. They were related to technical, economic, administrative and legal aspects but also with communication, chain development and commercialisation. With regard to the technical aspects/management, the stakeholders recognised the lack of knowledge they have to manage AF components and therefore, they requested information about the right and wrong combination of components (crops, trees and shrubs, animals, etc.) as well as about incompatibilities of crops with allopathic tree species e.g. walnut trees, eucalyptus, etc.). Attendees agreed that basic guidelines on how to establish AF systems are needed.

With regard to the woody component, they asked for better knowledge about best practices on 'tree management' (pruning, fertilisation, tree spacing, tree protectors, eco-treatments) considering the effects they have on arable and grassland production. They also showed interest in the best trees for longer term grassland and arable productivity and which are better adapted to climate change. They were keen to protect nature and animal biodiversity, but also want adequate measures to protect their herds so they requested information about fencing against predators (with a cost-effectiveness analysis). Finally, they were very interested in knowing about how AF can improve water management (e.g. ameliorate drought risks). Stakeholders were also interested in economical aspects as a key point to establish AF in their lands and also asked for an environmental cost benefit analysis. They were interested in the initial costs of establishing the systems and in the expected increase in biomass they will obtain. They were also interested in the development of models to indicate the potential reduction in grassland or arable crop production that may occur and the tree species that will be more profitable to minimise the loss

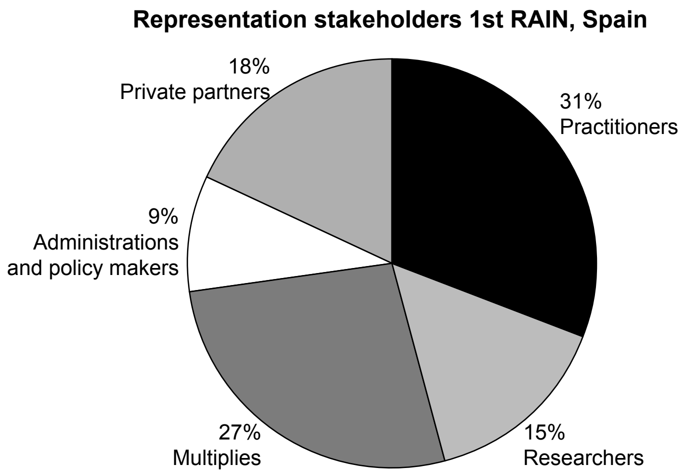

Figure 1. Representation of stakeholders attending the 1st RAIN, Galicia, Spain.

of understory biomass production. Moreover, the stakeholders felt that any initiatives to commercialise activities related to 'AF label' cooperatives or direct selling, or valuing AF products were also highly relevant. They found that a connection should be established between AF products and the need to value and improve ecosystem services, which are not currently considered. For this purpose, they think that cooperatives or direct selling could be good potential options.

They specifically found that Agricultural policies (e.g. CAP) penalise AF practices. They also think that there are incompatibilities with other regulations. Moreover, they think that Galicia does not have a clear strategy for regional land uses or specific policy measures to promote AF. They also found that there is a need for more training on legal and administrative aspects linked to AF.

The strong need for further communication and raising awareness among farmers and consumers was also highlighted by the RAIN stakeholders. They were unaware of the existence of guidelines and training material or experimental/pilot projects. They concluded that AF is unknown by the general public. They proposed innovative solutions such as an online map with AF farms/experiences, training materials and initiatives (including all aspects from technical to business and legal matters).

Conclusion

Stakeholders found a large number of drawbacks for AF promotion which were mainly technical (tree-crop compatibility and management) but also social (AF benefit awareness) and political (promotion and incompatibilities of current policies). Economic AF aspects at short, medium and long term were also requested.

Acknowledgements

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Knowledge transfer through the CAFRE dairy herd

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Abstract

The College of Agriculture, Food and Rural Enterprise (CAFRE) dairy herd at Greenmount Campus consists of 180 Holstein dairy cows managed in a relatively high input – high output system. The herd is managed to transfer knowledge to both students and dairy farmers in the management skills necessary to achieve high levels of milk solids production from efficient utilisation of grazed grass and silage. Cows in the herd are grazed from mid-March to mid-November. Strong emphasis is placed on ensiling high quality grass and forage maize silage to minimise concentrate feed use during winter months. Ongoing knowledge transfer projects centred on the CAFRE dairy herd include: 24 month replacement heifer rearing; dairy cow breeding; dry and transition cow management; energy efficiency; winter and summer feed efficiency; lameness prevention; SCC and mastitis reduction; and slurry utilisation.

Keywords: knowledge transfer, dairy, sustainability, efficiency

Introduction

The College of Agriculture, Food and Rural Enterprise (CAFRE) is an integral part of the Government Department of Agriculture, Environment and Rural Affairs (DAERA) and exists to transfer knowledge to both new entrants to the agri-food industry and to managers and staff of agri-food industry businesses across the country. CAFRE does not have a research remit. To deliver knowledge transfer to commercial farmers and growers, CAFRE have four teams of Dairying Development Advisers based in DAERA offices across Northern Ireland and a team of Dairying Technologists and Business Technologists working on knowledge transfer projects and dairy farm financial benchmarking based at Greenmount Campus.

Underpinning research behind the CAFRE knowledge transfer projects has been conducted by a range of research institutes including the local Agri-Food and Biosciences Institute (AFBI), UK and EU research institutes and recognised R&D from other dairying regions across the world. The key objective of CAFRE technology projects is to apply a combination of research findings, knowledge transfer and management skills into a package of associated 'technologies' that can be adopted in whole or part by practicing farmers and growers. Technology projects are demonstrated through the CAFRE dairy herd. Data and results from the CAFRE dairy herd are used as templates to demonstrate key project technologies to farmers and students both at Greenmount Campus and on Business Development Group (BDG) participant farms across the country. Discrete project technologies for adoption within a farm business may take the form of:

- analytical services;
- management practices;
- decision support tools;
- industry recommended lists and reports;
- investments in new equipment or infrastructure;
- optimisation of equipment performance.

Table 1 illustrates how the series of technologies associated with the summer feed efficiency project can be categorised.

Table 1. Summer feed efficiency project technologies.

Technology	Technology categorisation
Adjusting concentrate feeding to grazing conditions	Management practice
Grass cover measurement and budgeting	Management practice
Grass quality monitoring	Analytical service
Grazing infrastructure upgrading	Investment in infrastructure
Stocking rate and grazing area allocation	Management practice
Use of extended grazing techniques	Management practice
Use of Grasscheck predictions to manage grass cover	Management practice
Use of online grass budgeting tools	Decision support tool
Zero grazing	Investment in new equipment

Knowledge transfer measurement

Assessing the impact of knowledge transfer programmes is a challenging process. Over the past 20 years, CAFRE have developed methodologies for data capture on technology adoption on commercial farms through a farm 'Development Plan' application and through online monitoring of the use of decision support tools on the DAERA website.

The CAFRE 'Development Plan' application has been developed in-house to manage the knowledge transfer process. CAFRE Development Advisers work with farmers through peer learning BDGs which meet eight times annually to discuss dairy farm management topics. Farmers have contact with their CAFRE Development Adviser both through the BDGs and also on a one-to-one basis where a farm 'Development Plan' is drawn up based on the farm strengths and weaknesses identified through farm financial benchmarking. Key objectives are identified within the farm 'Development Plan' to improve the farmer's knowledge, skills and practices to improve the performance of the business. On an ongoing basis, the adoption of appropriate technologies required to meet the development plan objectives are recorded within the application. The farm 'Development Plan' application is also used to capture evidence of technology adoption to enable the technology adoption process to be audited internally and externally.

CAFRE decision support tools on the DAERA website are accessed by farmers through an 'Online Services' login system for which farmers must register. Once registered, the farmer may log in using a secure password. When logged in, the farmer has access to a range of DAERA services including animal registration, Basic Payment Scheme application and CAFRE decision support tools. Each time a farmer uses a decision support tool, a database is populated, indicating the date on which a farmer used a CAFRE decision support tool.

Results and discussion

Adoptions of technology on a dairying technology project basis for the most recent year to 31 March 2017 are presented in Table 2. The number of recorded technologies adopted within the year are considered to be an underestimate due to a limited time available for CAFRE Development Advisers to carry out one-to-one farm 'Development Planning' activities.

The potential for online monitoring of the impacts of knowledge transfer programmes is illustrated by the data in Table 3. A total of 536 individual farmers used CAFRE decision support tools on at least one occasion during the period. The highest use was of the footbath calibration application which coincided with lameness management and footbathing being the subject of 18 BDG meetings (279 farmers) during the period.

Table 2. Adoption of technologies by project 2016 - 2017.

Technology project	Number of technology adoptions
Dairy cow breeding	52
Dry cow management	0
Energy efficiency	3
Lameness prevention	45
SCC reduction	23
Replacement heifer rearing	14
Slurry utilisation	1
Summer feed efficiency	142
Winter feed efficiency	100
Total dairying technology adoptions	380

Table 3. Use of CAFRE Decision Support Applications 2016 - 2017.

Application	Number of individual farmers
Grazing management applications	85
Cost of forage	22
Dairy cow gross margin	35
Footbath calibration	259
Forage maize site suitability	13
Forage stocks	17
Milk production from grazed grass	22
Milk production profiler	25
Ration evaluation	16
Relative feed valuer	14
TMR M+	19
Variable speed vacuum pump payback calculator	9
Total decision support tool use	536

Conclusion

A methodology for measuring the impact of knowledge transfer programmes has been developed and applied by CAFRE.

The influence of an Irish sheep monitor farm programme in terms of practice change

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Abstract

Historically, farmers have been slow to adopt new technologies. This study focused on the influence of the BETTER Farm Sheep Programme (BFSP), a Teagasc run monitor farm programme in terms of practice change. Semi-structured and structured interviews, plus whole farm physical and financial analysis were used to investigate this influence. Between year one and year three on the BFSP, the participants, known as BETTER farmers, increased the number of lambs weaned ha^{-1} by an average of 16%. This accounted for an average increase of 31% in gross margins. The greatest improvement made by the BETTER farmers was in relation to grassland management. After joining the BFSP, they adopted, on average, more than half of the grassland management technologies researched. In addition, BETTER farmers also influenced other members of their discussion groups (45%) to modify grassland management practices and/or to adopt new technologies. Among their most significant influences was the creation of additional paddocks and rotational grazing. Newer members to the discussion group were more likely to be influenced to change. In conclusion, this study found that the BFSP can influence an increase in the adoption of grassland management technologies among the BETTER farmers and the farmers in their associated discussion groups.

Keywords: BETTER Farm, monitor farms, influence, practice change

Introduction

Monitor farms began in New Zealand in the 1980's (Jack, 2016) with the aim of improving productivity and profitability on commercial farms over a three year period (Beef & Lamb New Zealand, 2012). In Ireland, Teagasc established the BETTER (Business, Environment and Technology through Training, Extension and Research) farm sheep programme (BFSP) in 2008. The BFSP provides a forum where technologies developed from the Teagasc sheep research centre in Athenry, County Galway, and elsewhere, can be demonstrated and monitored to quantify their benefits in a commercial setting (Lynch, 2012). BETTER farmers have been shown to increase their gross margins ha^{-1} by 152% over a three year period and 58% of this increase can be attributed to increased productivity alone (Lynch *et al.,* 2013).

Monitor/BETTER farmers receive tailored advice and can learn by trialling new practices, assessing the results and modifying the practice(s) if necessary. For these reasons, it is likely the monitor/BETTER farmer benefits more than the wider farming community in terms of learning and the adoption of new practices (Prager and Creaney, 2017). However, it was hypothesised that the presence of BETTER farmers would improve the adoption of technologies by the wider sheep sector (Lynch *et al.,* 2013). Practices implemented on the BETTER farms can be seen by farmers in the BETTER farmers' discussion group as well as other Teagasc clients and non-clients through organised farm walks, open days and demonstrations (Mannion, 2016). Previous studies (Campbell *et al*., 2006; Watson Consulting, 2014; Prager and Creaney, 2017) give an indication that changes have taken place on monitor/BETTER farms and/or that they have influenced other farmers to change. The current study aimed to quantify: the number of changes made by BETTER farmers; increased productivity and financial performance; the level of influence in terms of practice change on their peers; what technologies were adopted by both parties. This paper focuses on the grassland management technologies in particular.

Materials and methods

This study used a mixed methods approach. Firstly, semi-structured interviews were conducted with the BETTER farmers (n = 8) in July 2016 on their farms. The interviews were recorded using a dictaphone (Olympus VN-2100PC) and relevant qualitative data was transcribed. Quantitative data from the interviews was inputted into Microsoft Excel 2010. Secondly, structured interviews (n = 69) were conducted with members of the BETTER farmers' discussion group. One of the BETTER farmers interviewed was relatively new on the programme and the discussion group had not visited his farm, therefore, they were omitted from the study. Random samples of ten farmers were selected to participate, where possible, from each of the remaining seven discussion groups. These farmers received questionnaires and were interviewed via telephone. Questionnaire data was inputted into the Statistical Package for Social Science (SPSS) for statistical analysis. Thirdly, semi-structured interviews with the BETTER farmer's advisors (n = 8) took place in May 2017 and were recorded using the Teagasc internal communication interface, 'Microsoft Lync'. The relevant qualitative data from these interviews were also transcribed. Finally, in May 2017, profit monitor data from five of the eight BETTER farmers were analysed. To allow for comparisons, data from two of the farmers were omitted as they were already analysed in a previous study. Data from a third farmer were omitted as he had not completed three years on the BFSP. The parameter used to assess increased productivity was the number of lambs weaned ha^{-1}. The first year of participation in the BFSP was set as the base year. The contribution of increased productivity was calculated by comparing the actual change in gross margin to what the change would have been if there was no increase in productivity from the base year. This is referred to as 'no gains'. The base year costs were inflated in accordance with the CSO agricultural price index, 2016 (prices change from year to year). Financial and performance data were accessed through the Teagasc e-profit monitor system. Microsoft Excel 2010 was used for statistical analysis.

Results and discussion

The stated motivation to join the BFSP was primarily to learn. The provision of intensive advisory support accelerated technology adoption in addition to giving them the confidence to make changes. The greatest number of changes made was in relation to grassland management. Each farmer made an average of 4.75 changes (range 3 - 7) in relation to their grassland management practices after joining the BFSP. The eight grassland management technologies evaluated were: grass measuring, grass budgeting, rotational grazing, the creation of more paddocks / temporary divisions, a closing plan in the autumn, reseeding, soil testing and silage testing. In July 2016, when the interviews were conducted all of these technologies were being practiced by all of the BETTER farmers. The most commonly adopted technologies after joining the BFSP were: grass measuring (n = 7), grass budgeting (n = 8), rotational grazing (n = 7) and the creation of more paddocks/temporary divisions (n = 6). Analysis of the e-profit monitors (n = 5) highlighted that the number of lambs weaned ha^{-1} on the BETTER farms increased by an average of 16% between year one and year three. This increased productivity led to an average increase in gross margins of 31% in year three (Table 1). Changes were also made in relation to breeding, flock health and financial management as well as farm facilities. Therefore, increased productivity cannot be attributed to the adoption of the aforementioned grassland management technologies alone.

In terms of practice change, six of the eight advisors felt that the area of grassland management was where the BETTER farmers had the greatest influence on other discussion group members. This viewpoint proved to be accurate as 45% of the farmers who completed a structured interview indicated that they were influenced by the BETTER sheep farmer in their group to make a change in relation to grassland management. The creation of more paddocks/ temporary divisions (15%) is where the greatest influence

Table 1. Summary of increased productivity and financial performance on the BETTER farms.

Parameter	Year 1	Year 2	Year 3
Average number of lambs weaned ha^{-1}	12.54	14.02	14.93
Average actual gross margin (€)	275	466	700
Average 'No-gains' (€)	275	291	480
Average gross margin increase from productivity (€)	0	175	220

was documented followed by rotational grazing (6%). Interestingly, the newer members of the discussion group were more likely to be influenced to change.

Conclusion

This study highlighted that the Teagasc BETTER farm sheep programme accelerates technology adoption among the BETTER sheep farmers, with a large number of technologies adopted after joining the programme. Furthermore, these changes have increased productivity and financial performance on the BETTER sheep farms. Although the greatest benefit of the programme is realised by the BETTER farmers themselves, they do help accelerate practice change among their discussion group peers. Therefore, it can be concluded that grassland management technologies and indeed other technologies can be successfully promoted to the wider farming community through the use of monitor/BETTER farms.

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A new curriculum to effectively transfer grazing knowledge to students

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Keywords: curriculum, dairy, education, grazing, students

Introduction

In several European countries, grazing management of dairy cows is seen as a weak point in the study program of agricultural schools and (applied) universities. The focus in these curricula is more on 'in farm' topics like breeding and animal nutrition. At the same time, more and more European stakeholders see grass-based systems as essential in producing food while delivering other ecosystem services such as biodiversity and carbon sequestration. As part of farmers entrepreneurship, grasslands will obviously only be maintained if they can be profitably used. Hence, the education of present and next generations of grassland farmers and advisors in grassland and grazing management is essential to achieve the benefits of grasslands.

Materials and methods

A new grassland and grazing curriculum was developed for agricultural students from vocational to bachelor level. The focus of this curriculum is knowledge transfer and to inspire the next generation of farmers and advisors with fundamental knowledge, innovations and application to practice. An analysis has been made of Dutch and international developments on grazing knowledge and tools using literature and information from practice. All relevant developments have been incorporated within this curriculum. Knowledge is transferred via lessons in class, training on the university farm and (international) farm visits and guest lectures for inspiration. In addition to that, knowledge is put in practise in close collaboration with commercial dairy farmers that are inspired by our students and vice versa.

Results and discussion

Important components of the curriculum are: (1) closing the gap between theory and practice by putting the knowledge gained directly into practice (on commercial dairy farms, e.g. by measuring in the field, analysing and advising and for some by managing the university farm); (2) the inclusion of strategic, tactical and operational training; (3) the involvement of national and international partners from advisory services, science and industry thus creating a learning network; and (4) different layers going from the basics to innovations and specialisation in grassland and grazing. This resulted in a new step by step integration of fundamental knowledge, applied knowledge and inspiration via new ideas, tools and concepts from (international) practice for 1000 students each year.

Conclusion

The new curriculum was evaluated by specialists from the field (farmers, advisors), teachers and students and leads to effective knowledge transfer, development of competences and inspiration to improve grazing. The 1000 students correspond to about 50% of total livestock students in the Netherlands on applied universities and vocational school programmes that will get better education in grazing management via this curriculum.

'Out in the field': supporting grassland management through discussion groups

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Abstract

Research undertaken in Ireland suggests that successful extension to support farmers' grassland management involves a process where: (1) goals are set; (2) confidence is generated; and (3) on-going support is provided. Farmer discussion groups can enable this process to occur and have been used throughout the world, in all agricultural sectors, as a method to support peer-to-peer learning. Ultimately, successful discussion groups enable dairy farmers to share ideas and to learn from each other's experiences/ perspectives. Teagasc research has shown that the five key drivers crucial to the success of discussion groups are: (1) membership and group organisation factors; (2) trust and security; (3) group solidarity; (4) facilitation and learning drivers; and (5) enjoyment and fun. This paper presents this research and an associated method for facilitators and group members to enhance their group functioning.

Keywords: discussion groups, facilitation, peer-to-peer learning

Introduction

Teagasc research has shown that, on average, the adoption of a range of technologies is higher by discussion group members than by non-discussion group members (Hennessy and Heanue, 2012). The farmer discussion group is a core operational strategy of public and private agricultural extension worldwide and in Ireland, is the delivery model for one of the largest publically funded extension programmes nationally. As with all forms of agricultural extension, farmers' learning and implementation of new knowledge does not occur in a linear process, where information is transferred in the direction of 'expert' to 'farmer'. As Vanclay (2004) explains, 'farmers are their own scientists, theorising, hypothesising and experimenting to determine what works'. In this context, 'farmers discussing their ideas with other farmers' is a crucial social process in which the adoption (or non-adoption) of new knowledge occurs (Vanclay, 2004).

The social process that characterises all instances of farmers' internalisation of new knowledge is directly supported by the nature of the discussion group venue (Macken-Walsh *et al.*, 2017). Group facilitators can use participatory techniques to facilitate the setting of individual and group goals. Peer-to-peer relationships within and beyond discussion group meetings allow farmers to deliberate and potentially gain confidence in each other's farm management practices and technology-use 'out in the field'.

Discussion groups must ensure that the social processes on which their effectiveness is reliant are functioning optimally. Therefore, knowledge of the constituent relational group dynamics that support these social processes is needed so that conscious efforts can be made by extension professionals to promote the dynamics. In this regard, the current paper presents an analysis that identifies 'five ingredients for success' and a practical method for group facilitators and members to promote these ingredients.

Materials and methods

A successful discussion group, in operation for over 20 years, self-nominated for case study research on the basis that they believed that much could be learned by other groups from the way in which they worked and were facilitated. The group had 12 members and all were dairy farmers, milking on average

120 cows per farm. Their facilitator had data pertaining to the farmers' farm management and technology use, which indicated that all were operating at a high level of technical efficiency. All group members were implementing recommended grassland management practices including extended grazing, on/off grazing, grassland measurement and data driven grassland decisions. In the views of both the farmers and their agricultural advisers, the group provided considerable peer-to-peer support.

A qualitative focus group was conducted to explore members' subjective experiences of their group's functioning. Three interviews were conducted with facilitators of the group (including former facilitators) to explore their perceptions of how the group functioned. For the focus group, exploratory research techniques were utilised to elicit a group narrative concerning the functioning of the group. Specifically, a subject-centred exploratory approach was used, based on the Biographic Narrative Interpretive Method (BNIM, Wengraf, 2001) where members were induced to 'tell the story' of their group, following which 'particular incident narratives' (PINs) were probed. Once the focus group data were analysed, the results were presented to the group. Participatory techniques were used to encourage members to interrogate the analysis with a view to incorporating amendments suggested by the group, with no significant amendments arising. Five key 'ingredients for success' were identified by the results and, using participatory learning and action methods with a group of experienced facilitators, a discussion-group self-appraisal method was co-designed and piloted.

Results and discussion

Five 'ingredients' for successful group dynamics were identified, which are listed below and illustrated by an accompanying user-centred perspective (quotation) (Table 1). Practical approaches to foster these five factors, identified by specialists and advisers through the co-design process, are also listed (Table 1).

A self-evaluation method, which involved group members' individual reflections on and group discussions of how their group were achieving the ingredients for success was also co-designed and piloted. Once members had individually reflected, the method involved each member using round coloured stickers to indicate their answers to multiple choice questions on a flipchart sized poster. The poster, once populated with the coloured stickers, provided a visual aid to assist groups to identify key areas requiring attention or improvement. The method was piloted by advisers not involved in the research or co-design process. Feedback suggested that the method was intuitive and easy to implement and that it stimulated a rigorous and thorough discussion of group functioning.

Conclusion

The five ingredients for success and associated practical facilitation tips, are consistent with contemporary extension research findings internationally, all of which emphasise the non-linear nature of farmer learning in extension and the reliance of farmer learning on relational dynamics – both between peers in farmer discussion groups and between advisers and their farmer clients (Mofakkarul-Islam *et al.,* 2011). Once a well-functioning relational group dynamic is in place, groups will be better positioned to interrogate, debate and apply new knowledge in an empowered way. It is also consistently emphasised in the contemporary extension literature that the design of agricultural technologies and management practices should involve not only scientists, but the inputs of end-users (farmers, advisers) in a co-design process. We applied this principle to the design of an extension method, which, as envisaged by the extension literature, resulted in a product that was 'more suitable, appropriate, easier to adopt and developed more rapidly' (Triomphe, 2012). The farmers who participated in this case study have improved their grassland management skills through their membership of a well-functioning discussion group. The lessons learned from their experiences are equally applicable within all discussion groups.

Table 1. Factors for discussion group success and techniques to foster them.

Ingredient	Techniques/ facilitation tips
Membership and organisation	Carefully select members, supporting members' self-selection and inter-peer selection
'We might be all different as individuals but our group	Facilitate group members to forge shared goals
has common goals. We as members believe in and	Facilitate organisation of members into sub-groups and encourage such sub-groups to take ownership
commit to these goals'	for group tasks
	Leverage the skills of individual group members while ensuring connectivity and relevance to other
	group members
	Hold an annual general meeting to review and plan group activities
	Aim for clarity surrounding the timing of meetings
Trust and security	Establish a positive, challenging culture at group meetings, while avoiding 'destructive criticism'
'We feel that we can speak openly and truthfully	Promote truthfulness and discourage 'one-upmanship'
without feeling that what we say might be derided'	Use benchmarking appropriately: consider anonymised codes initially until members are comfortable
	with full disclosure
Enjoyment and fun	Don't underestimate the social aspect to meetings: a 'cup of tea' before /after the meeting
'Fun makes taking part a more positive experience and	Build relationships through a field-trip or social occasion away from home, ideally organised by
good relationships are conducive to sharing challenges'	members themselves
Solidarity	Facilitate the adoption of a group name, shared group goals and group routines
'One for all, and all for one'	Arrange a pre-visit to the host farm so as to maximise the farm as a learning resource, considering the
	needs of the group
	Promote a culture of helping each other in times of difficulty
Facilitation and learning drivers	Facilitators should have both facilitation and agricultural production expertise with the facilitator
'Aside from creating a good group learning	introducing additional expertise to the group as required
environment, we have access to different types of	Increase the level of shared responsibility over time
expertise through the group, which is necessary to	Group members must have realistic expectations: group facilitation is different to one-to-one advice
make the best decisions for our farms'	The facilitator must remain independent and impartial

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Assessment of on-farm hypocalcaemia prevention protocols for pasture-based dairy herds

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Keywords: hypocalcaemia, pasture-based, dairy

Introduction

Management practices to control (sub)-clinical hypocalcaemia in peripartum dairy cattle are well understood and include adequate dietary Mg content, prevention of excessive body condition score (BCS) gain in late gestation and control of dietary K concentration (Mulligan *et al.*, 2006). From a knowledge transfer perspective, a primary challenge is to provide simple protocols that can be readily implemented at farm level to achieve these management goals. While a majority of Teagasc dairy discussion group clients have reported adequate control of hypocalcaemia, individual herds report persistent issues despite ostensibly similar management. Our objectives were to improve understanding of hypocalcaemia management on these farms by assessing current control practices and to test whether improvements could be achieved by implementing protocols agreed by the farmer, adviser and veterinarian.

Materials and methods

A cohort of herds (n = 16) reporting high rates of hypocalcaemia was selected in conjunction with Teagasc dairy extension officers. Herd managers were interviewed to determine current management practice. Forages were analysed for nutritional and mineral composition. Body condition score per cow was recorded at drying off and calving. Blood samples were taken from 8 - 10% of mature cows per herd at 24 - 36 hr post-calving for analysis of plasma mineral (Mg, Ca, P) content. Revised management plans for each farm were co-designed by the farmer, veterinarian and extension officer, to correct management issues identified during herd investigations; outcomes were recorded. The relationship between forage K content and mean plasma Ca content at calving was tested using simple regression.

Results and discussion

The majority of study herds (0.75) did not practice forage mineral analysis, while 0.125 used BCS to aid decision-making on feeding dry cows. Mineral supplementation was not adjusted based on forage analysis on 87.5% of farms. Increased forage K content in late gestation was associated with lower herd mean plasma Ca content ($R^2 = 0.30$, $P < 0.05$); this was identified as a risk factor for hypocalcaemia. Subsequent to agreement of revised protocols, reduced rates of clinical milk fever and retained foetal membranes were reported by 0.50 and 0.44 of farms respectively. Implementation of agreed protocols was variable, particularly with regard to BCS management.

Conclusion

Co-designed protocols modifying peripartum dietary K, Mg supplementation and BCS, improved control of hypocalcaemia in dairy herds identified as having high incidence rates.

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Research and farming working together to develop grassland varieties resilient to extreme weather events to mitigate climate change

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Abstract

Extreme weather events like flooding and drought are becoming more prevalent as the effects of climate change begin to impact. To increase resilience to these, grass and clover breeders at IBERS are working to develop plants with stronger, deeper root systems and improved root-soil interactions leading to greater water-use-efficiency and improved soil hydrology. Certain *Festulolium* (ryegrass × fescue species' hybrids) have been shown to reduce surface run off by increasing soil porosity and enhancing soil-water retention. Using participatory research and working with industry partners, eight commercial development farms were selected to cover a range of soil types, geographical areas and livestock sectors (ruminant and mono-gastric) across the UK. Two 1 ha areas of single variety grass leys: *Festulolium* (cv AberNiche) and hybrid ryegrass (cv AberEve) were established in accordance with standard farm practice. The field performance of these novel grasses and clovers has been monitored by farmers and researchers together to study whether changes in individual plant design, when reproduced at the field scale, can deliver future resilient grassland varieties that provide excellent forage for livestock and improved soil hydrology.

Keywords: *Festulolium*, ryegrass, soil hydrology, resilient grassland

Introduction

Research Scientists at Aberystwyth's Institute of Biological, Environmental and Rural Sciences (IBERS) and Rothamstead Research North Wyke in Devon have been working to develop new grasses that combine the agronomic qualities that farmers are looking for with new characteristics that mitigate and adapt to meet some of the challenges of climate change. Many areas of the UK have experienced significant flooding events in recent years and if rainfall run-off could be captured or reduced by improvements to grassland soils, farm businesses and the environment would benefit. MacLeod *et al*. (2013), reported a 51% reduction in run-off where a perennial ryegrass (*L. perenne*) × meadow fescue (*F. pratensis*) hybrid had been sown in a two year field experiment. The SUREROOT project builds on this work by breeding grasses and clovers with better rooting structures, to improve water-use-efficiency and to change soil hydrology.

Materials and methods

Eight commercial development farms were selected to cover a range of soil types (clay, loam, silt and sand), geographical areas and livestock sectors (sheep, beef, dairy, poultry, pigs and turkeys). Two 1 ha areas of single variety grass leys: *Festulolium* (cv AberNiche) and hybrid ryegrass (cv AberEve) were established in accordance with their standard farm practice. During 2015 and 2016, farmers recorded soil temperatures and rainfall on the 1 ha *Festulolium* and ryegrass areas and researchers visited the farm sites in the spring and autumn to assess these areas, scientifically, and through discussions with the farmers. Root biomass (10 cm soil cores taken to a depth of 70 cm at each sampling point in the field followed by washing and sieving to remove and clean the root before drying and weighing) and water infiltration (a metal ring hammered into the ground to a depth of 3 cm and filled with a known volume of water: the time taken for the water to seep into the soil was used to calculate water infiltration rate (cm h^{-1}) was monitored. The data were derived from the mean of three sampling points in each of the 1 ha grass areas on each farm site.

Results and discussion

Festulolium root biomass was numercially higher in the top 50 cm of the soil profile at farm sites with sandy and sandy loam soils after one year when compared to the ryegrass areas. On other farm sites, root biomass was either similar or was higher (one farm site) on the ryegrass area after one year, which may have been due to differences in soil type.

On all farms, water infiltration was higher for *Festulolium* areas (30.7 cm/hr; s.e.m 5.87) compared to the ryegrass areas (16.6 cm hr^{-1}; s.e.m 2.1) in the autumn. Water infiltration rates were lower in the spring compared to autumn across all farms and differences between the *Festulolium* and ryegrass areas were less evident.

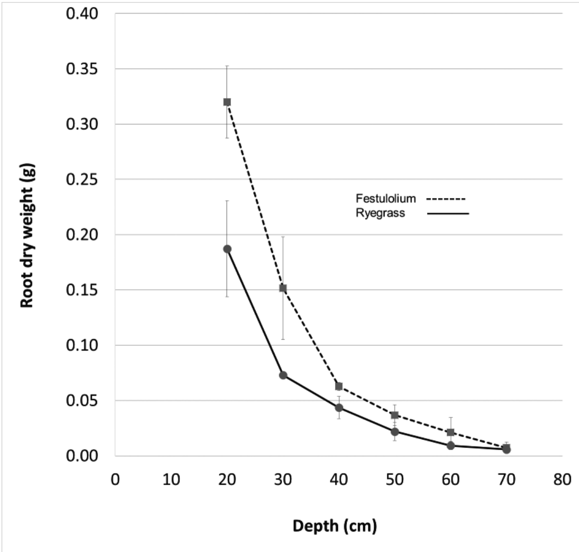

Figure 1. Root biomass of *Festulolium* and ryegrass on sandy soil farm type.

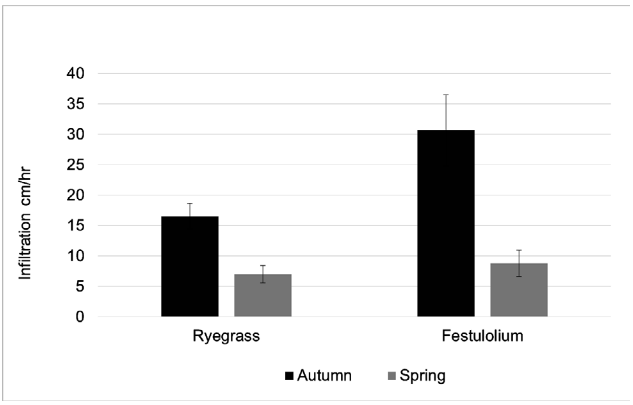

Figure 2. Water infiltration (cm hr^{-1}) across all farm sites in both spring and autumn for the 1 ha ryegrass and *Festulolium* areas.

Festulolium and ryegrass varieties were grown on diverse farm types across the UK that represent different soil types, topography and receive different volumes of rainfall annually. The abiotic and biotic stresses that these varieties experience varies significantly between the sites. Grasses and soils are being evaluated in response to these stresses in the SUREROOT project; 2015 - 2019). Data collected from monitoring activities undertaken by both the farmers (e.g. field management activities) and researchers e.g. soil profiling, measurements of compaction, bulk density assessments, soil coring and water infiltration, gives us an indication of root growth and depth following establishment and also the effect this root growth has on the soil. Whilst *Festulolium* root biomass was not greater than ryegrass root biomass on all farms, it is the characteristics of the root growth that are of interest to farmers and researchers alike; when *Festulolium* roots senesce, it leaves the soil more porous and increasing the permeability of the soil facilitates the movement of water down through the soil profile (MacLeod *et al*., 2013). During this first phase, it was observed that water infiltration rates were higher in the *Festulolium* areas (30.7 cm hr^{-1}; s.e.m 5.87) compared to the Ryegrass areas (16.6 cm hr^{-1}; s.e.m 2.1) in the autumn.

Conclusion

Although the grass variety evaluation on farms was done as single species swards and so, as such, is not yet 'best practice', it engages farmers with new variety development and engenders a feeling of ownership with an opportunity for robust feedback to research. Progress in grass breeding and the development of new varieties as they come to market as grass varieties are the cornerstone of farm enterprises. A *Festulolium* grass variety that combines the forage quality of an Italian Ryegrass with the rooting characteristics of a Fescue has been found to be of interest to the industry. Establishing participatory farmer activity by ensuring farmers have been actively-engaged in monitoring the soils and grasses used on their own farms and learning about the data collated by the research team has allowed for optimal integration between industry and science, ensuring that farmers feel part of the project. To date, the SUREROOT project findings suggest that *Festulolium* (cv AberNiche) has improved water infiltration rates and greater root biomass in some soils. The research will continue to evaluate grass and clover varieties that provide excellent forage for livestock and improved soil hydrology through participatory research that is relevant to farmers as end-users of scientific innovation.

Acknowledgements

The SUREROOT project is BBSRC and industry funded science developing improved rooting systems in grasses and clover for sustainable livestock systems and for ecosystem services.

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Establishing national benchmarks of N and P balances and use efficiencies on Irish grassland farms

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Abstract

Improving grassland agriculture sustainability requires minimising nutrient balance (NB) surpluses and increasing nutrient use efficiencies (NUE). To set targets for improved farm nutrient management, benchmarks were established by farm sector and production intensity using 1,379 nationally representative farms from the Irish National Farm Survey. Annual farm-gate NBs (kg ha^{-1}) and NUEs (%) for nitrogen (N) and phosphorus (P) were calculated from import/export data from 2008 to 2015, inclusive. Quantile regression analysis and percentile rankings were used to identify benchmark farms with the lowest surpluses per production intensity (kg N or P exported ha^{-1}), highest NUEs and highest gross margins (€ ha^{-1}). Large differences in NBs between farms of the same sector and production intensity indicate considerable potential for improvements. For example, benchmark dairy farms maximised productivity (median export 55 kg N ha^{-1}), NUE (median 31%) and gross margins (median €2,593 ha^{-1}) whilst keeping surpluses low (median 124 kg N ha^{-1}) via lower fertiliser and concentrate feed imports and higher stocking densities (median 2.1 livestock units ha^{-1}). Using benchmarks as targets to encourage improvements in nutrient management could help farms achieve this potential and assist in achieving national objectives for sustainable agricultural production.

Keywords: benchmark, balance, nutrient use efficiency, sustainability, nitrogen, phosphorus

Introduction

Grassland agriculture faces the challenge of achieving sustainable production that meets EU water quality and greenhouse gas emissions targets. Ireland is currently experiencing agricultural intensification as a result of the government agri-food strategy (Food Wise, 2025) and the abolition of milk quotas in 2015, but this must be achieved in an environmentally sustainable way. Intensive agricultural production relies upon nitrogen (N) and phosphorus (P) imports in the form of chemical fertiliser and feed, but relatively low proportions of these costly non-renewable nutrients are converted into agricultural products. The remainder are largely lost to the environment, contributing to eutrophication, climate change and other environmental impacts. Reducing nutrient surpluses on farms and increasing nutrient use efficiencies is, therefore, critical in reducing the environmental impact of agriculture and improving farm profitability (a win-win) (Buckley *et al.*, 2016; Mihailescu *et al.*, 2015). Establishing benchmarks as targets for farm nutrient management performance could be an effective strategy to motivate improvements.

Materials and methods

Annual N and P balances and use efficiencies (key performance indicators of nutrient management) were calculated for 1,379 nationally representative grassland farms from 2008 to 2015 (inclusive) using import and export data collected by the Teagasc National Farm Survey (part of the European Farm Accountancy Data Network (FADN)). Nutrient balances (kg ha^{-1}) were calculated by measuring nutrient imports onto the farm through the farm-gate in the form of chemical fertiliser, feed and livestock, and subtracting nutrients exported in agricultural products (milk, wool, crops and livestock). Nutrient use efficiencies (%) were calculated by dividing nutrient exports by imports. Sectors represented included dairy, mixed livestock, suckler cattle, non-suckler cattle and sheep. Gross margin (€ ha^{-1}) data were acquired for analysis of farm economic performance.

Farms with unsustainable nutrient deficits that would not meet agronomic or livestock nutritional requirements (< 3 kg P or < 0 kg N ha^{-1}) were removed prior to benchmarking analysis. Data were analysed using quantile regression to fit percentile regression lines to the relationship between production intensity (kg export ha^{-1}) and nutrient balance (kg surplus ha^{-1}). Benchmark farms were identified as those below the 75^{th} percentile (Q75) line with the lowest N or P surpluses for a given production intensity. Gross margin percentile rankings were then used to establish an optimal benchmark zone. Nationally representative benchmarks for each sector and soil type (3 classes) were established in this way.

Results and discussion

Using dairy as an example, Table 1 can be used as quantitative targets by farmers and policymakers to improve nutrient management. Results show that as production intensity (total exports) increases, nutrient surpluses use efficiencies and gross margins tend to increase. However, benchmark farms achieve high production intensity and gross margin at a relatively low surplus compared to poorer performing farms, making these farms more environmentally and economically sustainable. This was due to higher milk yields, lower total imports of chemical fertiliser and concentrate use, smaller land area, and higher stocking density. Large ranges in balances between farms at the same production intensity show potential for improvements.

Figure 1 allows a farm to compare performance relative to its peers within the same sector and soil type and set farm-specific benchmark targets. However, due to constraints outside a farmer's control (e.g. environment or farm fragmentation), it may not be possible for all farms to reach optimal benchmark zone targets. Therefore, aiming for the next-best zone of performance (below the next lowest regression line) may be a more reasonable and achievable goal. To reach it, a farm can either (1) lower its nutrient surplus, (2) increase its exports, or (3) do both. Potentially, maximum surpluses could also be set as a policy measure using the Q10 (10^{th} percentile) regression line in order to reduce excessive surpluses from the 10% worst performing farms (located above the line).

Table 1. Median N balances, use efficiencies, imports, exports and farm characteristics of benchmark dairy farms relative to poorer performing groups.

			Optimal zone	Benchmark		Above average	Below average	Worst	
Performance	N balance	percentile	76-100	91-100	76-90	51-75	26-50	11-25	1-10
	Gross margin	percentile	76-100	1-100	1-100	1-100	1-100	1-100	1-100
Key performance indicators	N balance	kg N ha^{-1}	124	63	103	131	168	206	254
	NUE	%	31	36	28	23	20	17	14
	Gross margin	€ ha^{-1}	2,593	1,484	1,828	1,818	1,817	1,832	1,812
Farm variables	Utilised area	ha	49	46	51	54	55	52	53
	Stock density	LU ha^{-1}	2.1	1.4	1.7	1.8	1.9	2.0	2.1
N imports	Fertiliser	kg N ha^{-1}	136	77	110	133	165	199	243
	Concentrates	kg N ha^{-1}	31	19	26	30	33	38	44
	Forage crops	kg N ha^{-1}	2	1	1	1	1	3	3
	Livestock	kg N ha^{-1}	0.0	0.0	0.2	0.1	0.1	0.2	0.2
	Total imports	kg N ha^{-1}	176	103	144	172	209	249	298
N exports	Milk	kg N ha^{-1}	43	23	29	31	32	33	34
	Wool	kg N ha^{-1}	0	0	0	0	0	0	0
	Cash crops	kg N ha^{-1}	0	0	0	0	0	0	0
	Livestock	kg N ha^{-1}	8	6	8	7	8	8	8
	Total exports	kg N ha^{-1}	55	36	40	40	41	43	43

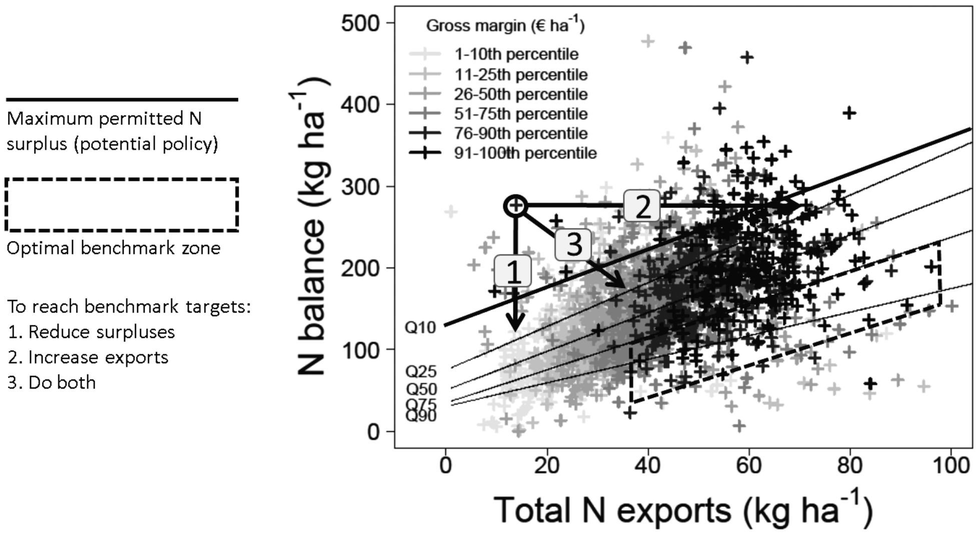

Figure 1. Relationship between total N exports and N balance for dairy farms. Percentile regression lines of the relationship (Q10 - Q90) are plotted to indicate performance zones. Gross margin percentiles are indicated by colour to identify an optimal benchmark zone.

Conclusion

National benchmarks of NBs and NUEs were established for dairy, beef and sheep sectors using data from 1,379 National Farm Survey farms in Ireland. Benchmark farms maximised NUE and gross margins whilst keeping surpluses low, mainly due to lower fertiliser and concentrate feed imports, higher exports and higher stocking densities. Using benchmarks as targets to encourage improvements in nutrient management could reduce environmental losses and increase profitability (a win-win), aiding national Food Wise 2025 objectives for sustainable agricultural production.

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