

Producing milk from grazing to reconcile economic and environmental performances

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Abstract

Several reports, directives, regulations and initiatives challenge high-input dairy systems at the environmental level. At the same time the dairy sector has to adapt to a greater volatility of prices and to the projected increase in energy and fertiliser prices. In this new context, it should be considered whether the model of development based on intensification, often in connection with the reduction in the use of grazing, is always well adapted. Dairy systems that maximise grass utilisation appear to be highly competitive and the various roles of grassland in providing regulating and supporting services are now widely recognized. Thus grassland should form the basis of more sustainable dairy systems in the future, provided technical innovations are produced to improve the efficiency of grassland-based dairy systems. Innovations in forage production, innovations in characteristics of the cows and management of lactations, as well as innovations in the management of the system have potential for increasing economic and environmental performances of grassland-based systems. The more systematic use of legume forages in multi-species swards makes it possible to reduce the consumption of mineral N, to reduce the carbon footprint of the dairy system, to regularize the forage production over the year and to increase the nutritional quality of the forages. It clearly appears that intensive selection for milk based on high concentrate diets has generally resulted in genotypes that are not well suited for systems maximising forage utilisation. In these systems there needs to be a special focus to address fertility, survival and other functional traits such as mastitis resistance, although high genetic merit for milk should be maintained to produce efficient responses to concentrate supply. Finally, extending the grazing season with early turnout or late grazing, and tactical use of grazing in association with conserved forages in large herds, offers many opportunities to reduce the requirement of expensive conserved forage and to reduce the utilisation of purchased feeds. All these potential sources of progress are discussed.

1. Introduction

High milk prices have encouraged dairying systems using high inputs of chemical fertilizers, concentrate feeds and mechanised methods for silage production at the expense of grazing. The use of grazing for milk production has decreased considerably over the last 30 years (Bourgeois, 2002) and the number of cows which are kept indoors for all or part of the herbage growing season has increased considerably in many European countries (Van den Pol-van Dasselaar *et al.*, 2008). These tendencies were largely reinforced by the convenience of managing dairy herds indoors particularly with cows calving in autumn and fed with maize silage, whereas dairy farmers have many difficulties to organize the feeding programme of grazing dairy herds in time and space from an unstable feed resource. For forty years the selection of dairy cows has been almost exclusively oriented toward genetic potential for milk production. Today, high genetic merit Holstein cows are able to produce more than 10000 kg milk per lactation in high-input farming systems but can not produce such an amount of milk

from grazing alone. This has largely contributed to reduce the use of grazing, especially in countries in the North of Europe. More recently, the increasing use of automated milking systems also makes grazing more difficult, although the combination of grazing and milking robot is possible (Wiktorsson and Spörndly, 2002). Increased herd size may be another reason for the decreasing of grazing, at least for countries in the North of Europe where pressure for land use and stocking rate are high.

The context has gradually changed since the early 1990s primarily with the emergence of environmental regulation considering water quality in a first step (the Nitrate Directive, the Water framework Directive) and the agri-environmental measures will become gradually more restrictive and will define new priorities. Apart from nitrate, ruminant production systems are also considered to be responsible for the emission of large quantities of greenhouse gases (FAO, 2006; Steinfeld *et al.*, 2006). More recently the projected fall or instability of price of milk and the projected price increase of non-renewable energy and mineral fertilizers will reinforce the necessity to engage a new era of development. This new context offers new opportunities for dairying systems based on grasslands and grazing. Indeed, grazing is not only a relatively cheap source of feed for ruminants but grasslands are increasingly recognised for their contributions to the conservation of biodiversity, regulation of physical and chemical fluxes in ecosystems, the mitigation of pollution, and especially carbon sequestration which might partly counteract methane emissions from ruminants, and also the protection of soils (MEA, 2005). Additionally, grassland-based systems promote a clean, animal welfare-friendly image for ruminant production, and open landscapes with grazing ruminants are highly appreciated by the public. The objective of this paper is to review existing knowledge for developing productive, efficient and environmentally friendly dairying systems based on grazing and grassland utilisation and using level of inputs as low as possible.

2. Improved grassland utilisation can increase sustainability of dairying systems

2.1. Grassland utilisation has many assets to combine economic and environmental performances

The comparisons made at the world level show that dairying systems maximising grassland utilisation appear to be highly competitive. A study of international competitiveness (Fig. 1) shows that the total cost of production is negatively related to the proportion of grass in the cow's diet (Dillon *et al.*, 2008). This cost is therefore 50 to 60% higher in Denmark and in The Netherlands than in Ireland, whereas France and UK are intermediate. For similar climatic conditions grazing is still more economically attractive than indoor-feeding systems. Models indicate that in Ireland early grazing will generate an increased profitability of € 2.70 per cow and day for each extra day at grass, through higher animal performance and lower feed costs (Kennedy *et al.*, 2005). Similarly in the Netherlands, the more grass the cows eat at pasture the larger is the farmer's income. Only in situations with more than 10 cows ha⁻¹ grazing surface is indoor feeding more profitable than grazing (Van den Pol *et al.*, 2010).

Using life cycle assessment, Basset-Mens *et al.* (2005) have shown that global warming potential per kg milk is 30 to 80% lower in the New Zealand dairying systems, which rely essentially on permanent white clover-grass pastures grazed all around the year than in conventional intensive dairying systems encountered in Sweden and in southern Germany (0.72 vs. 1.2 kg kg⁻¹ CO₂ eq per milk) which rely mainly on conserved forages and high amount of concentrates. Organic dairy Swedish systems and extensive dairying systems in Germany are intermediate (1.0 kg kg⁻¹ CO₂ eq per milk). It is also noticeable that total consumption of non-renewable energy is reduced in grassland-based systems. This might confer a decisive advantage to these systems in the case of high price of energy in the future.

In the study of Basset-Mens *et al.* (2005), total consumption of energy is two times less in New Zealand systems than in intensive European dairy systems. Le Gall *et al.* (2009) have calculated that energy consumption to produce one kg of milk decreases from 5.0 MJ for intensive dairy farms in Netherlands to 4.0 for French farms using maize silage and fertilised grasses pastures to 3.1, and to 1.4 for Irish systems based on fertilized ryegrass pastures and 1.4 for NZ farms. Increasing the proportion of grassland in arable land linearly decreases the utilisation of pesticides as shown in the European project Greendairy (Raison *et al.*, 2008).

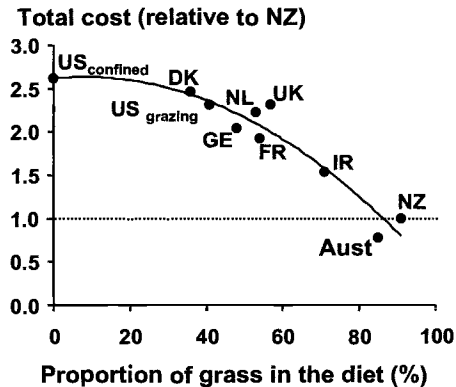


Figure 1. Total cost (expressed relative to New Zealand costs) of milk production according to the proportion of grass in the annual diets of the cows (adapted from Dillon *et al.*, 2008)

2.2 Technical innovations are required to enhance the sustainability and competitiveness of grassland based dairying systems

Dry matter (DM) intake and milk yield of grazing dairy cows are limited compared to conserved forage-based diets (Kolover and Muller, 1998). High genetic merit cows are able to eat more grass and the marginal increase of daily intake with genetic merit for milk covers approximately two-thirds of the additional energy requirements associated with the increase in milk potential (Peyraud *et al.*, 2004). Consequently, a grassland-based system prevents high genetic merit cows from fully expressing their milk potential despite high amounts of concentrate being provided. However, several trials have shown that relatively high milk production (i.e. 7400 kg per lactation) is achievable with high genetic merit cows in grassland-based systems with only 350 kg of concentrate (Buckley *et al.*, 2000; Kennedy *et al.*, 2002; Horan *et al.*, 2005; Delaby *et al.*, 2010) at least under areas well suited for giving high yields of grass over a prolonged grazing season. Herbage allowance is one of the primary factors influencing herbage intake (Peyraud *et al.*, 2004) and high herbage allowance is required to achieve maximum intake and milk yield per cow. The implication is that grazing systems designed to maximise individual animal performance are inefficient in utilisation per ha. To solve the dilemma of a high herbage intake per cow versus high utilisation of herbage per ha, sward structures and grassland management allowing the maintenance of a high intake together with a low residual sward height must be determined.

There is a large variation both between and within countries in the grass-growth season and expected yield and the contribution of pasture to the total energy supply should vary, but in all cases grazed forage must be at the maximum to reduce the cost. The length of the grass-growing season varies from about 5 months in the north Europe to up to 11 months. Grass grows regularly from the spring to autumn in the western part of Europe (UK, Irish Republic, Normandy in France). The most favourable regions with humid summers have a DM yield potential of 15000 kg ha⁻¹ and of 20000 kg ha⁻¹ milk (Holmes, 1980; Delaby and Peyraud,

1998). In other regions the grass growth curves are usually characterised by having a summer drought during most of the years, which obliges farmers to house their animals, or a cold spring; these limitations reduce the grazing season to 4 or 5 months and DM yield to 5000 or 6000 kg ha⁻¹. Grazing also suffers from the difficulties of management. The feed resource is not stable during the season and there is large inter-annual growth curve variability. Therefore, animal performances may be variable and this is not well accepted by farmers. The use of on/off grazing that means combination between restricted access time to pasture and indoors feeding should be investigated to increase grassland utilisation and reduce variability of animal performances, even for systems having a very high stocking rate and short grass-growing season.

The relative importance of the multiple functions provided to society by grasslands varies depending on regional contexts, grassland type and type of management. It is not well known how well the different grassland management systems and their localisations perform in delivering ecosystem services. In particular, the role of grazing on regulation of N flows is questionable. It is well established that much higher amounts of N are leached from grazed pastures than from cut pastures, mainly because of animal-N depositions as direct returns on the field (Decau *et al.*, 1997; Wachendorf *et al.*, 2004). Under highly fertilized pure-grass pastures relatively large amounts of nitrate may be leached and there may be relatively large emissions of nitrous oxide (N₂O). Losses of N₂O-N up to 29 kg ha⁻¹ yr⁻¹ have been reported on Irish grassland receiving 390 kg ha⁻¹ yr⁻¹ N (Hyde *et al.*, 2006). Estimates of N leached from grazed pastures vary widely. Summarizing data from New Zealand, France and Denmark, Ledgard *et al.* (2009) have shown that nitrate-N leached remains below 50 kg ha⁻¹ yr⁻¹ so long as total mineral N inputs are lower than 300 kg ha⁻¹ yr⁻¹. In Europe, many dairy production systems are to a large extent based on ley-arable rotations that are characterized by three phases: pasture, ploughing out and subsequent arable cropping (Vertès *et al.*, 2007). These systems present more important risks of nitrate leaching than the systems based on permanent grassland as shown in the European project Greendairy (Raison *et al.*, 2008) and they require a great technical control to reduce the nitrate losses to the minimum. The release of accumulated soil N following pasture cultivation often exceeds 100 kg ha⁻¹ (Vertès *et al.*, 2007; Eriksen *et al.*, 2008).

3. Multi species swards with forage legumes (MSS) should form the basis of more sustainable dairy systems

Difficulties in maintaining well-balanced mixtures and the tendency to lose key species in multi species swards (MSS) (Guckert and Hay, 2001) contribute to the prevalence in temperate grasslands of grass monocultures, with associated significant inputs of synthetic fertilisers. Yet legumes can have an important contribution in sustainable ruminant production systems in the future. They potentially allow the reduction of inputs of purchased mineral N and concentrate N, considering their ability to use atmospheric N for producing home grown proteins and their high nutritional value.

3.1. Multi species swards increase productivity compared to pure grass pastures

A pan-European experiment was carried out at 28 sites in 17 countries across Europe. At each site, the two most important forage grasses and the two most important forage legumes were tested and the management of the swards followed local recommendations for best agricultural practice. Monocultures and mixtures of the four species were managed at the same cutting frequency and the same fertilizer inputs. The results (Fig. 2) showed strong benefits of grass-clover mixtures containing four species as compared to these species sown in monoculture (Kirwan *et al.* 2007; Lüscher *et al.*, 2008) for all sites. There was even

significant transgressive over-yielding for most of the mixtures (higher yield than best monoculture yield). For the mid-European and north-European sites, all the mixtures yielded more than the best monoculture. This occurred even though mixtures were sown with widely varying species proportions (from 10 to 70% for each species). This result persisted over the 3 years of the experiment, with transgressive over-yielding being 6%, 20% and 16% in years 1, 2 and 3 respectively.

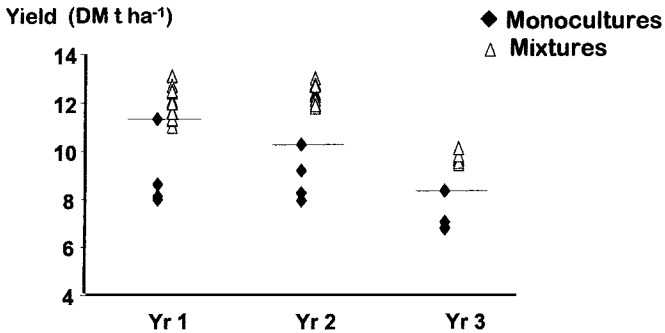


Figure 2. Total dry matter (DM) yield across sites of four monocultures (◆; horizontal dotted lines indicate the maximum) and 11 grass-legume mixtures with strongly varying species proportions (△) for harvest year 1 to 3 (adapted from Kirwan *et al.*, 2007).

Yield benefits of grass-clover mixtures are equivalent to 150-350 kg ha⁻¹ fertilizer N. Comparing the yield of heavily N-fertilised grass swards with the yield of moderately fertilised grass-clover mixtures illustrates the potential N fertiliser savings associated with grass-clover mixtures. At the Swiss site in Zurich, additional plots were sown alongside the pan-European experiment to investigate the effect of three N fertiliser levels (50, 150 and 450 kg ha⁻¹ yr⁻¹ (Nyfeler *et al.*, 2009). Grass-clover mixtures fertilised with 50 or 150 kg ha⁻¹ yr⁻¹ N attained yields in the range of the heavily fertilised (450 kg ha⁻¹ yr⁻¹ N) monocultures of the highly productive grass, with clover percentage in the mixture ranging from 30 to 80%. To define more precisely the potential of the grass-clover mixtures compared to pure grass stands for the different soil and climatic conditions encountered in the west part of France, more than 400 fields on commercial farms were monitored for several years (Institut de l'Elevage, 2004). The study confirms that the productivity of mixed pastures is directly related to the contribution of clover. The DM production of grass-clover mixtures increases by 7.2 to 7.9 and 9.2 t ha⁻¹ for clover contributions of, respectively, less than 20%, 20-40% and 40-60% in summer. On good and deep soils and with a sufficient water supply in summer, mixed pastures produce almost as much DM as the pure grasses pastures receiving 200 to 250 kg ha⁻¹ (9.6 vs. 9.8 t ha⁻¹). In dry conditions, grass-clover mixtures produce less than pure stands because the reduction or cessation of growth during summer does not make it possible to compensate for the latespring start of production of mixed pasture.

Using grass-clover mixtures also offers the possibility to extend the herbage growth season. Characteristic within-season growth patterns favour the grasses in spring, during reproductive growth, and the legumes in summer when temperatures are high (Lüscher *et al.*, 2005). Thus the production of mixed pastures is generally shifted about the summer. At the opposite, a major objective of grass breeders is to increase the length of the growing season of ryegrass, and increased productivity of new ryegrass variety is mainly due to slightly longer growth period and there is no indication that any limit has been reached from continuous selection (Wilson, 1993).

3.2. Multi-species swards can sustain high animal performances

At grazing, herbage intake is higher on grass-clover mixtures than on pure stands. In the studies conducted in Rennes (Ribeiro Filho *et al.*, 2003; 2005), mixed pastures steadily increased DM intake and milk yield (on average 1.5 kg d⁻¹) whatever the level of herbage allowance. Besides the positive effect of legumes on voluntary intake, which is well established (INRA, 1989), it is also probable that leaves of legumes are more favourable for prehension than stems and sheaths of grasses. Thus Ribeiro-Filho *et al.* (2003) have reported that higher intake on white clover-grass pastures is mediated through a higher rate of intake on mixed pastures compared to pure perennial ryegrass pastures. One of the most decisive advantages of white clover is that the rate of decline of nutritional quality throughout the plant-ageing process is far less than for grasses (Peyraud, 1993; Dewhurst *et al.*, 2009). At grazing, the difference in DM intake between pure grass pastures and grass-clover mixtures increases with increasing age of the regrowth. Ribeiro-Filho *et al.* (2003) showed that herbage DM intake declines by 2.0 kg d⁻¹ on pure ryegrass pastures compared to 0.8 kg d⁻¹ on mixed pastures. This makes mixed pastures easier to manage than pure grass pastures. Age of regrowth can be increased without adverse effect on quality.

Increasing the content of white clover in pasture has increased milk yield by 1-3 kg per cow per day in several short-term trials conducted at similar herbage allowance (Philips and James, 1998; Ribeiro Filho *et al.*, 2003). The difference increases with clover content and reaches a maximum when white clover content averages 50-60% (Harris *et al.*, 1998). As a consequence of higher energy intake, milk protein content tends to increase on mixed pastures.

3.3. Multi-species swards have potential for reducing negative effects of intensive dairying systems on the environment

Forage legumes have potential for reducing nitrate leaching to some extent. This was well illustrated by Ledgard *et al.* (1999, Table 1) who measured the N inputs and outputs and N flows over three years in a trial involving three dairy farmlets (i.e. the herd and the experimental area required to feed the herd). The results clearly indicate that, from an environmental point of view, the intensively managed grass-clover mixtures are relatively efficient in terms of conversion of N inputs from N₂ fixation into milk, and in reducing N surplus at the field level. N in milk averaged 45% of N inputs for the 0 N farmlet compared with a value of only 22% for 400 N farmlet. Ledgard *et al.* (1999) have also quantified the different routes of N surplus. Leaching of nitrate-N was minimal for the 0 N farmlet and increased very rapidly with the level of fertilisation. Losses of N by denitrification remained small but were reduced on white clover-grass pastures. Nonetheless, it might be expected that N-nitrate leaching, and thus eutrophication potential, would rise with increasing legume content and thus level of N₂ fixation per hectare. Loiseau *et al.* (2001) have reported higher leaching losses from lysimeters when swards were sown with pure white clover (28 to 140 kg ha⁻¹), whereas the losses from ryegrass-white clover swards were lower than 20 kg ha⁻¹ over the 6 years of the experiment. Similarly, in the study of Ledgard *et al.* (1999), the amount of nitrate-N leached varied greatly (20 to 74 kg ha⁻¹) in the ryegrass-white clover paddocks and these variations are linked to the N₂ fixation by white clover. On ley-arable rotations, ploughing grass-clover mixtures can release large quantities of N, and fertilizer-N on subsequent cereal crops must be reduced to a minimum (Ledgard *et al.*, 2009) to reduce the risk of nitrate-N leaching.

Ruminant livestock production systems relying on grass-clover mixture utilisation have potential for reducing the consumption of non-renewable energy. Energy efficiency, calculated as herbage net energy produced per MJ of non-renewable energy consumed is 3

times higher for white clover-grass pastures compared to fertilised grasses pastures (17.7 kJ NE vs. 5.7 kJ NE/MJ new renewable energy, NE calculating according to INRA 1989; Besnard *et al.*, 2006). In New Zealand conditions, Basset-Mens *et al.* (2009) have shown that energy consumption per kg milk is 59% lower on a farmlet receiving 0 kg ha⁻¹ mineral N than on a farmlet receiving 140 kg ha⁻¹ mineral N. It is also noticeable that Basset-Mens *et al.* (2005) have shown, using LCA analysis and IPCC emission coefficients, that total energy consumption per kg of milk is two times less in New Zealand systems, which rely essentially on permanent grass-clover mixtures, than in intensive European systems using large amounts of fertiliser-N and concentrates.

Using grass-clover mixtures also reduces total greenhouse gas emissions and global warming potential per kg milk. Using Life Cycle Analysis, Ledgard *et al.* (2009) have shown that total greenhouse gas emissions per kg milk were 10% lower for 0N farmlets than for 207 N farmlets. In Sweden, Cederberg and Mattson (2000) have showed lower greenhouse gas emissions in organic systems using grass-clover swards than in conventional systems. Global warming potential of N₂O is very high (310 times higher than that of CO₂). This raises the question of N₂O emission factors for grass-clover mixtures compared to using N-fertilizer. Available data are very rare. It appears that emissions might be smaller for mixed sward (0.2 vs. 1.3% N; Corré and Kasper, 2002) but this should be confirmed by further experimentation.

Table 1. Annual N flows (kg yr⁻¹) for 3 dairy farmlets varying in N fertilizer and white clover content (adapted from Ledgard *et al.* (2009))

Farmlet	A	B	C
N fertilization	0	200	400
Stocking rate (cows ha ⁻¹ y ⁻¹)	3.3	3.3	3.3
Inputs			
Mineral fertilizer	0	215	413
N ₂ fixation	174	117	40
Others	5	6	5
Outputs			
Milk and meat	80	95	98
Harvested forages	1	15	28
Transferred excreta ¹	57	78	84
N surplus	41	150	248
Denitrification	5	15	25
Volatilisation	16	38	61
Leaching	40	79	150

¹ Transfer of N from the paddock to the lanes and milking shed via cow excreta

4. Appropriate cows for successful temperate grassland-based systems

Until very recently the Holstein cow has been selected almost exclusively in high-input farming systems, with milk production and cow conformation being the predominant breeding-goal traits. Today, the genetic merit for milk potential makes it possible to obtain high performances by using well managed grassland-based systems and low levels of concentrate. Several trials have shown that it is possible to reach 7000 kg of milk per lactation, or even more, with Holstein cows in compacted spring-calving systems while supplying less than 500 kg of concentrate (Kennedy *et al.*, 2002; Horan *et al.*, 2005; Delaby *et al.*, 2009b). However, it is now well established that cows selected solely on milk have poorer fertility performances. This negative effect observed on high-input systems might be exacerbated in low-input grassland-based systems. Therefore the improvement of genetic merit for milk production does not appear any more to be the unique objective. The question of the suitability of high genetic-merit cow (HGM cow) and the place of alternative breeds for grassland-based systems must be asked (Dillon *et al.*, 2006).

4.1. Improvement of cow fertility is a key issue for efficient grassland-based dairying systems

Several trials have compared cow genotypes in grassland-based systems. Most of the studies were conducted in Ireland (Dillon *et al.*, 2003; Horan *et al.*, 2005, 2006; McCarthy *et al.*, 2007) and in France (Delaby *et al.*, 2009b, 2010) under compacted spring-calving seasonal systems. These experiments have all shown that HGM cows always produce more milk even on low-input systems. But HGM cows were also characterized by degraded reproductive performances for all indicators of fertility traditionally monitored (intervals to first service, pregnancy rates, and no-return rates). In particular the rate of culling was strongly increased for HGM cows (Evans *et al.*, 2006). This is well illustrated by the experiment of Dillon *et al.* (2003) who compared the performance of high genetic merit cows (Dutch genetics), Irish Holstein with a lower genetic merit for milk, and French Montbeliarde and Normande over a 5-year period with 137 lactation per breed. The Dutch Holstein produced more milk but significantly more Dutch Holstein cows were not pregnant at the end of the reproductive period. Reproduction performances of Irish Holstein cows were intermediate and the best results were obtained with the dual-purpose breed. Finally, after 5 years of experimentation, only 20% of the Dutch cows survived compared to 50% for the dual-purpose breed.

The undesirable side effects of high genetic merit for milk on reproduction and survival do not seem to be counteracted by adjustment of the management. Several trials have been conducted to explore the cow genotype x system interactions. Concentrate supplementation (Kennedy *et al.*, 2003; Delaby *et al.*, 2010) or an offer of more abundant grass (Buckley *et al.*, 2000; Horan *et al.*, 2004) did not correct for genetically induced inferior fertility of HGM cows. The additional nutrients provided are used to produce additional milk with no effect on reproductive performance in HGM cows. Increasing the rate of involuntary culling results in inflated replacement costs and might eliminate part of the economic benefit that can be achieved from selection (Evans *et al.*, 2006). Increasing the rate of culling also implies a need to increase the number of dairy cows to produce the same amount of milk, as younger cows are present in the herd and that first lactating cows produce less than adult animals. We have simulated that increasing the replacement rate from 20 to 35% in a herd of 100 cows will require an extra of 4 cows to produce the same amount of milk. This will increase the requirements of forage and thus of grassland area and will increase the emissions to the environment. Younger cows are also less efficient in their ability to convert forage into milk because intake capacity increases with the rank of lactation (Faverdin *et al.*, 2007).

It should be noted that infertility problems are less acute when compact calving is not required. This is the case when high quality forages are available all around the year, for example when maize silage can be used in periods of low or nil grass growth. In these situations the production of one calf per cow per year is not an absolute objective, and other lactation management can be considered. Lengthening of lactations, with a desired delayed first artificial insemination, offers several advantages such as reducing the non-productive periods and limiting the inherent risks associated to the beginning of lactation. This is not yet a common practice although 90000 lactations were recently recorded in Brittany, with 11200 kg milk over 440 days (Trou *et al.*, 2009). However, this strategy requires cows having a high persistency of lactation and success at first service, and low embryonic mortality still remains a key objective even if first service is voluntarily delayed.

4.2. The ideal cow should be able to quickly adjust her level of production to the economical conditions

Although grassland-based systems prevent HGM cows from fully expressing their milk potential, this does not remove the need for having animals of good milk potential especially

in a context of fluctuating prices to adjust the level of production to the current situation. In periods of high milk prices (as it was the case in 2008) it could be efficient to produce more milk by increasing the supply of concentrate. A good genetic potential for milk production guarantees an efficient milk response (about 1 kg of milk per kg of concentrate; Peyraud and Delaby, 2004). Horan *et al.* (2006) and McCarthy *et al.* (2007) have shown that compared to highproduction North American cows, NZ cows have a much higher pregnancy rate: only 7% of NZ cows were not pregnant at the end of the breeding period compared to 26% of the HGM cows, but NZ cows have also low response to supplementation. The milk response to concentrate was 0.4 for NZ cows compared to 1.1 for HGM cows.

The objective would be in the long term to have animals expressing their ability to produce milk primarily by a good persistency of the lactation and with a moderate peak of lactation. This will limit the energy deficit and associated pathological troubles at the beginning of lactation while making lactation management on grassland easier. In the future, genomic selection will make it possible to select on the persistency of lactation, something that is not possible with the traditional methods of selection.

4.3. Are others breed more sustainable than Holstein cows to maximise grassland utilisation?

In theory the most efficient animal is that which produces the maximum of milk per kg of live weight, because the needs for maintenance are then diluted in a higher level production thus giving theoretical advantage to small animals. Several studies have reported that Jersey cows were more efficient at converting grass DM into milk solids than Holstein cows. Grainger and Goddard (2004) reported that production efficiency is 6% higher in Jersey than in Holstein cows. More recently, Prendiville *et al.* (2009) reported that Jersey are 11% more efficient than Holstein-Friesian cows. However, it is noticeable in this study that the Holstein-Friesian cows weighed only 500 kg, which is far lower than the weight of Holstein used in France and in the North of Europe (650 to 700 kg). Large cows produce generally much more milk than small ones. This means that at herd level more Jersey cows are required to produce the same amount of milk than a Holstein herd, and the advantage of small cows might be rather limited in practice. However, Thomet and Kunz (2008) support that the smaller cows are more effective in terms of production per hectare because they make it possible to increase the stocking rate. In their simulation, the dairy production increases by 6% with the smaller cows for the same stocking rate expressed in live weight per ha.

It is also advisable to reconsider the interest of the dual-purpose dairy breeds which have better milk composition and beef merit compared to Holstein cows. These breeds make it possible to produce 6000-7000 kg of milk per lactation mainly from grassland with very low amount of concentrates. Pregnancy rates were higher with Normande cows than with Holstein cows (Dillon *et al.* 2003; Delaby *et al.*, 2010) thus ensuring a limit of the culling rate for infertility problems and the replacement costs in seasonal compact calving systems. Moreover, dual-purpose breeds ensure a greater stability because of the double source of income (milk and meat). The economic comparisons of various systems does not show a clear advantage for specialised milk production systems compared to systems using a dual-purpose breed producing milk and meat (Evans *et al.*, 2004; Delaby and Pavie, 2008), at least in a fixed milk quota scenario.

5. Grassland and herd management for improving the proportion of milk produced from grazed forages

5.1. Increasing stocking rate to produce more milk per hectare

In most countries of Europe, pressure on land use is high and maximising milk yield per unit area is more than just a challenge to maximise profitability per hectare (Dillon *et al.*, 2008). In experimental herds, annual production of 15000 kg ha⁻¹ milk from grass, with less than 500 kg of concentrate, have been reported (Horan *et al.*, 2005). Stocking rate, defined as the number of animals per unit area of land during the grazing season, has been recognized for a long time as the most important factor governing milk output per unit area of pasture (Mott, 1960). A recent meta analysis including 131 comparisons of stocking rate concluded that an increase in stocking rate of one cow ha⁻¹ resulted in an increase in milk yield of 1650 kg ha⁻¹ (i.e. 20%) and milk solids of 113 kg ha⁻¹ while milk yield per cow decreased by 1.3 kg d⁻¹ and milk protein content by 0.5 g kg⁻¹ (McCarthy *et al.*, 2010).

The effects of feeding supplement on cow performance were reviewed by Peyraud and Delaby (2001). Efficient response of one kg of milk to one kg concentrate is now currently reached when the amount of concentrate per cow does not exceed 6 kg d⁻¹. Moreover, the efficiency of supplementation at grazing appears to be closely related to energy balance of the cows, and it increases when pasture intake is restricted through increased stocking rate, with economic returns depending of the concentrate to milk price ratios and most often positive. Therefore, feeding concentrate can be a very efficient tool to maintain a high stocking rate and thus good sward management, which allows the control of post-grazing sward height while achieving high milk yield per cow and per hectare with high economic returns.

5.2. Extending the grazing season to consume more grass while increasing cow performance

There is considerable opportunity to extend the grazing season, thereby reducing costs associated with indoor feeding systems. Given the high feeding value of grass relative to conserved forages, there is interest to extend the grazing season as much as possible. In many situations moderate grass growth occurs in early spring and herbage growth in late autumn is almost entirely lost through senescence and grass death during winter if not grazed. Experiments have been conducted from mid February to mid April in Ireland (Dillon and Crosse, 1994; Kennedy *et al.*, 2005), in Northern Ireland (Sayers and Mayne, 2001) with grass silage fed indoors, and in Brittany (O'Donovan *et al.*, 2004) with maize silage fed indoors. These experiments have all showed that access to grass for a few hours per day increased milk yield by 1 to 3 kg and reduced silage intake by 4 to 6 kg per day thus reducing the amount of conserved forage to be harvested and distributed. In the study of Kennedy *et al.* (2005) it is noticeable that early turnout of spring-calving cows to pasture in the early postpartum period resulted in a slight improvement of milk yield and milk protein content when compared to housed indoor cows fed with a TMR ration (44% grass silage). Extending the grazing season may also occur in autumn as shown by Mayne and Laidlaw (1995). The effective use of late autumn grass as part of the diet of dairy cows was further confirmed under Brittany conditions (Chenais and Le Roux, 1996). Cows having access to grazing during daylight (6 h d⁻¹) produced 1 kg d⁻¹ more milk and consumed 5.1 kg d⁻¹ less maize silage than cows fully housed. Obviously, during these transition periods daily grazing time and stocking rate should be adjusted according to the climatic conditions and soil types to avoid poaching and to limit the risk of nitrate leaching. The influence of extending the grazing season on N-nitrate leaching will be investigated during the FP7-EU-project MULTISWARD (Peyraud *et al.*, 2009).

Besides the positive effect on cow performances during the period of part time grazing, early spring grazing has a positive effect on herbage quality in subsequent grazing rotations. Early grazed swards contained a high proportion of green leaf, a lower proportion of grass stems and senescent material and are more digestible (O'Donovan *et al.* 2004; Kennedy *et al.*, 2006). Moreover, grass growth during the subsequent rotations was not affected by early grazing although pre-grazing sward height was lower and almost all grass that has been produced is grazed thus making the system very efficient (Table 2). Finally, early grazing in spring avoids large accumulations of herbage which can be difficult to graze and increases ease of grazing management for subsequent rotations.

Table 2. Effect of the date at turnout on the sward production and animal performance in spring grazing (from April to end of June) (adapted from O'Donovan *et al.*, 2004)

Date of first grazing	Early February	Late March
Sward height, 30 th March (cm)	5.5	10.0
Herbage DM growth (kg ha ⁻¹ d ⁻¹)	66	66
Pregrazing sward height (cm) ¹	11.8	15.2
Milk (kg d ⁻¹)	23.2	22.1
Herbage disappeared (kg d ⁻¹) ²	15.6	15.9
Herbage utilisation (% of growth)	100	85

¹ When cows enter to a new paddock

² Calculated as (H pregrazing – H postgrazing) x sward bulk density

5.3. Part time grazing to maintain grassland utilisation for large herds

Grazing becomes more complicated with increasing herd size. It is not the size of the herd by itself which is the most limiting factor because large herds (up to 400 cows or more) are grazing in England and in New Zealand. The difficulties rise from the increased area that is needed around the milking parlour for grazing. This is occurring in many regions or countries in Europe, especially in the most intensive dairying areas. In these situations where stocking rates are high, the time at pasture can be restricted to a few hours per day to maintain grazed forage in the diets. Part time grazing combined with restricted indoor feeding should be considered as an interesting alternative to reduce the amount of conserved forages which are always expensive to produce, and to keep as much as possible of the fresh forage for producing milk. Allowing the cows to graze for some hours per day can also improve the welfare of cows (Sairanen *et al.*, 2006).

When time at pasture is restricted, cows increase the proportion of time spent grazing and the pasture intake rate to partially compensate for the reduction of time at pasture. Large increase in rate of intake (more than 25%) were reported when access time decreased from 8-9 h to 4-5 h d⁻¹ (Kristensen *et al.*, 2007; Pérez-Ramírez *et al.*, 2008, 2009) However, these adaptations are insufficient to compensate for the large reduction of time at pasture. Some studies have shown that restricted grazing time to 4 h per day does not allow dairy cows to maintain milk production and herbage intake, in spite of a high rate of supplementation (Kristensen *et al.*, 2007). An experiment was recently conducted at Rennes (Delaby *et al.*, 2010) which examined the response curves to increasing levels of maize silage fed as a supplement to cows having access to pasture either 4 h (between morning milking and midday) or 8 h a day (between morning and evening milking) (Table 3). When the access time was restricted to 4h, 15 kg of maize silage were required to achieve high animal performances. When the access time was 8h, the response reached a plateau for 10 kg of maize silage. Feeding only 5 kg of maize silage did not allow the maintaining of animal performances. These results clearly show that the amount of supplementary forage must be adjusted to the access time. The level of supplementation will be chosen in order to maximise milk yield per cow or to maximise pasture utilisation.

Table3. Effect of the supply of maize silage on dairy cow's performances having a restricted access to pasture for grazing

Daily access time to grazing (h)	4			8		
Offered maize silage DM (kg d ⁻¹)	5	10	15	5	10	15
Maize silage DM intake (kg d ⁻¹)	5.8	11.2	15.5	5.8	11.1	14.4
Milk (kg d ⁻¹)	22.4	24.7	26.5	23.1	25.7	26.4
Fat content (g kg ⁻¹)	38.2	37.8	37.8	38.7	37.1	37.8
Protein content (g kg ⁻¹)	27.8	28.7	29.8	28.9	29.1	29.7

6. Conclusion

In the future, dairy systems should be more environmentally sound, economically viable and productive. Grassland with its multifunctional roles provides a good basis for developing more sustainable production systems in the long term. This paper show there is quite considerable scope to improve the performances of dairy systems based on grassland. Forage legumes in multi-species swards will undoubtedly constitute one of the pillars for the development of future dairy systems with high environmental and economic performances. Selection of functional traits for more robust cows and adaptations of lactation and system management will constitute the others pillars. The FP7 funded European project MULTISWARD (Peyraud *et al.*, 2009) will conceive, evaluate and promote sustainable ruminant production systems based on the use of grasslands with a high level of multi functionality in order to optimize the provision of environmental goods and biodiversity preservation, on one hand, and on the other, economic efficiency. To enhance the competitiveness and multi-functionality of grassland-based dairying systems, MULTISWARD will assess and optimize the roles and performances of multi-species swards and will design and evaluate innovations in grazing and animal management according to the possible ways of progress described in this paper. MULTISWARD will also identify and analyse the effects of several socio economic and policy scenarios on the future of grassland.

7. References

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