WAGENINGEN UR

Grassland resowing and grass-arable crop rotations

International Workshop on Agricultural and Environmental Issues
Wageningen, the Netherlands, 18 & 19 April 2002

J.G. Conijn, G.L. Velthof & F. Taube (eds)

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EGF European Grassland Federation

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Foreword

In Europe grassland is an important resource for animal husbandry, especially in dairy farming. Productive grass swards and nutritive grass are essential for economical dairy farming. To maintain these demands grassland is cultivated. Common strategies of cultivation are ploughing of grassland followed by reseeding or ley-farming. However, grassland cultivation is more and more challenged by increasing demands of legislation and society in terms of nutrient losses, conservation of biotic diversity, protection against erosion and carbon sink. Science is challenged to provide sustainable solutions.

The European Grassland Federation (EGF) is a forum to discuss issues related to grassland and to promote the interchange of scientific and practical experience between grassland experts. Within this framework the EGF Executive Committee has officially installed a Working Group on Grassland Resowing and Grass-arable Rotations at the 19th General Meeting which was held in La Rochelle, France, in May 2002. The working group was installed after the presentation of the results of a workshop on grassland cultivation. This workshop was held in Wageningen in April 2002 and was attended by more than twenty scientists from seven Northwest European countries. They discussed the current situation of grassland cultivation in the different countries and identified gaps of knowledge regarding agronomic and ecological effects of grassland cultivation. These gaps have to be bridged in the future.

It is a pleasure for me that the papers presented at the Wageningen workshop and the discussion results are published as a first report of the EGF Working Group ‘Grassland Resowing and Grass-arable Rotations’. The report gives a good overview of the present situation regarding grassland cultivation and the scientific questions which have to be addressed. I wish to thank the organising committee, especially the secretary J.G. Conijn and chairman F. Taube, for their efforts to have this report published. I hope that their fruitful work will continue and that more reports will follow. I also hope that this report will stimulate other scientists in Europe to participate in the Working Group to achieve progress all over Europe.

W.H. Prins
Federation Secretary
European Grassland Federation

Abstract

An international workshop on the agricultural and environmental aspects of grassland resowing and grass–arable crop rotations was held in Wageningen, the Netherlands, on 18 and 19 April 2002. Teams of research workers from seven countries in Northwest Europe had been invited to present the situation on grassland renovation in their countries and to discuss the knowledge gaps and research needs for the future. Countries that were represented: the Netherlands (initiator), Belgium, Denmark, France, Germany, Ireland and United Kingdom. These countries were invited because they all share more or less the same climatic conditions (at least in part of their countries) and that they all have more or less comparable grassland and farm management systems (i.e. high input and output). Because of the similarities in grassland conditions these countries face the same challenges in meeting the demands for agronomically and environmentally sound grassland systems. The emphasis of the workshop was placed on nitrogen processes (accumulation, losses and output), but participants were encouraged to share any relevant information on phosphorus, carbon (organic matter) and water use (groundwater recharge) related to grassland resowing and grass–arable crop rotations.

The first part of the workshop consisted of an oral presentation of each country in which the following aspects were addressed:

(1) General situation: key figures on the intensity of grassland use and grassland renovation in each country (if possible these figures were given per soil type or region). Information on legislation with respect to grassland use and grassland renovation, specific for each country, was also given.
(2) Farmer's practice: causes, criteria and methods for grassland renewal. Some countries were able to provide a full cost-benefit analysis of grassland ploughing and resowing.
(3) State of the art in research: sharing of the present understanding of the processes that occur around grassland renewal. Insights obtained from extensive experimentation were given, such as long-term experiments, feeding value of young/old grassland, nitrogen losses related to management, etc.

In the second part of the workshop four parallel sessions had been organised, where the participants discussed a number of topics related to the effect of grassland cultivation on N and P cycling (session I), soil quality and water balance (session II), crop and animal performance (session III), and farm management and economics (session IV). Knowledge gaps and research needs were the main issues in the discussions. The results of the discussions in the four sessions were reported in a plenary meeting and an overall discussion was held. Some highlights of each session:

I. **Nitrogen and phosphorus cycling.** There are many gaps in our current quantitative knowledge on N and P cycling, but much data probably has not yet been published in the international literature. Before new research is started, it is recommended that an overview of the existing data sets is obtained and that these data should be combined and analysed to assess their relevance. On the basis of this overview, conceptual models on nutrient cycling can be developed and the main gaps in our knowledge identified: proposals for further research can then be made.

II. **Soil quality and water balance.** Soil quality is difficult to measure due to the absence of a clear-cut definition. Many aspects are involved, such as carbon storage, physical characteristics, soil fertility, water supply and biodiversity/microbial activity. Some of these are known, at least qualitatively, but others are less well understood (such as soil compaction, water supply, pH effects and carbon storage). There is also a lack of knowledge about the optimum biodiversity in soils. Furthermore, society often has variable and conflicting demands with respect to soil quality.

III. **Crop and animal performance.** The absence of practical methods to judge the performance of a grass sward is hampering objective decisions on grassland cultivation. Gross crop production seems to be less important for the farmer who is more focused on grass quality,

estimated from ‘a look on animal behavior during grazing’. Temporary grassland is preferred if good performance of permanent grassland is difficult to maintain, like on dry sandy soils. Main question here is how to maintain the high performance after re-establishing grassland. Temporary grassland seems also to be preferred if clover is more appreciated.

IV. **Farm management and economics.** The costs of resowing in three countries range from € 365 to 623 per ha. The differences depend primarily on which inputs have been included in the analysis. Otherwise there are no large differences when comparing the costs of individual operations across countries. The relative costs and benefits depend on factors such as climatic differences and soil type within each country that affect the costs of production. For example, in Ireland a long grazing season is favoured by a relatively mild wet climate that is not particularly conducive to maize production with existing cultivars. On the other hand, in Denmark and Northern Germany milk production tends to be based on rotation of short-term grass leys and maize production, as grass swards show a rapid deterioration (within 3 to 4 years), due to unfavourable climatic circumstances. The situation in Belgium and the Netherlands is between the Irish grazing system and the Danish system of high nutritive forage. In order to properly assess the cost/benefit of grass to grass resowing it is necessary to have reliable data on the increased productivity (forage yield and nutritive value) that is directly attributable to resowing in the years following resowing.

The workshop ended with a plenary session on synthesis, conclusions and follow-up. An overview was presented on the knowledge gaps detected during the workshop which need further attention in future research. Some gaps, not mentioned above, are:

(1) awareness of the difference in the circumstances of farmer’s practice and experimental fields is needed to ensure a safe extrapolation of the data (primarily measured at experimental fields), and
(2) a whole farm approach and simple modelling efforts should be stimulated to gain relevant insights.

Each country presented an outline of the on-going research within the subject of grassland cultivation. Much emphasis is placed upon nitrogen processes in these research programs; other aspects, like phosphorus, water, biodiversity, etc., are not dealt with or only briefly investigated. With respect to plans for follow-up, a ‘permanent’ Working Group on Grassland Resowing and Grass-arable Rotations is to be installed at the EGF-2002 meeting in France. This will facilitate the continuation of the co-operation on research into grassland cultivation which started with this workshop. The aim is to present progress on the subject in a special session on grassland cultivation at the EGF conference in 2004.

General introduction

Economical dairy farming requires productive grass swards and nutritive animal feed. Grassland resowing and grass-arable rotations are important instruments in meeting these demands. However, grassland cultivation[1] also increases the risk of nutrient losses to soil and surface waters and to the atmosphere and may affect carbon storage and biodiversity. There is a strong demand for the development of measures and tools to achieve environmentally and agriculturally sound systems of permanent and temporary grassland.

A research programme focusing on the agricultural and environmental effects of cultivation of permanent and temporary grasslands started (2002-2005) in the Netherlands in January 2002. This programme is financed by the Ministry of Agriculture, Nature Management and Fisheries in the Hague and aims at obtaining quantitative insights into the effects of cultivation on crop yields and nutrient emissions to the environment. The programme includes experimental research, systems analyses, and the development of measures and tools for farmers.

An international workshop "Grassland re-sowing and grass-arable rotations" was organised in the context of this programme. This workshop was held in Wageningen in the Netherlands in April 2002 and was attended by more than twenty scientists from seven Northwest European countries, i.e. Belgium, Denmark, France, Germany, Ireland, United Kingdom (England and Northern Ireland), and the Netherlands. These countries were invited in view of the similarity in climatic conditions and in intensity of dairy farming systems.

Participants of the workshop (see Appendix I).

[1] In this report grassland cultivation is used as a common term for grassland renovation (grass is resown after different intensities of tillage) as well as for short term grassland in rotation with arable crops (ley farming).

The objectives of the workshop were to discuss the situation in the various Northwest European countries with respect to grassland re-sowing and grass-arable crop rotations and to identify research needs. The workshop was also used to seek opportunities for further future collaboration. The workshop focused on nitrogen, but the participants were encouraged to share any relevant information on phosphorus, carbon and water use related to grassland resowing and grass-arable crop rotations.

The first part of the workshop consisted of an oral presentation by each country in which the following aspects were addressed: i) general situation (key figures on the intensity of grassland use and grassland renovation in each country), ii) farmer's practice (causes, criteria and methods for grassland renovation), and iii) state of the art in research.

The second part of the workshop was formed by four parallel sessions during which the participants discussed a number of topics related to the effect of grassland cultivation on nitrogen and phosphorus cycling (session I), soil quality and water balance (session II), crop and animal performance (session III), and farm management and economics (session IV). Knowledge gaps and research needs were the main issues in the discussions. The results of the discussions in the four sessions were reported in a plenary meeting and an overall discussion was held.

This report presents the seven papers of the countries (Part I), the results of the discussion sessions (Part II) and Conclusions (Part III). A follow-up of this working group has been established within the framework of the European Grassland Federation (EGF). The EGF Executive Committee officially installed a Working Group on Grassland Resowing and Grass-arable Rotations at the 19th General Meeting which was held in La Rochelle, France, in May 2002.

Thanks are due to the Dutch Ministry of Agriculture, Nature Management and Fisheries for their financial support in organising the workshop and in publishing this report.

Part I. Oral presentations

1. Grassland renovation in the Netherlands; agronomic, environmental and economic issues

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Abstract

The Netherlands has a total grassland area of approximately 1 million ha, which is about 25% of the total land area. The majority consists of permanent grassland, but rotation with maize, potatoes and flower bulbs is found in certain regions. Grassland on sand, clay and peat soils is -on average- renovated every 5, 10 and 30 years, respectively. Generally, the motivation for grassland renovation is the poor agronomic performance of a sward, caused by factors as drought or winter damage, sometimes in combination with mismanagement. The costs of a standard grassland renovation range from € 550 ha^{-1} on peat soil to € 825 ha^{-1} on heavy clay soil. A cost-benefit analysis showed that grassland renovation is financially attractive if the new sward produces 10 to 25% more than the old sward. This suggests that farmers might have other motives for grassland renovation that have not been identified yet. Furthermore, scientifically sound and practically applicable criteria are needed to support farmers in decisions on grassland renovation.

Experimental studies into the effects of grassland renovation on environmental and agronomic parameters are scarce in the Netherlands. The effects of grassland renovation have been estimated for three cases of permanent grassland on sand, clay and peat soil, and an additional case for a grass-maize rotation on dry sandy soil. Although it is possible to determine the soil N balances for these cases, there is much uncertainty about the changes of soil organic N and the pathways of N losses. Therefore, there is need for a further quantification of the effects of grassland renovation on N cycling in the plant-soil system, with respect to soil type, renovation strategy and crop management.

Introduction

In the Netherlands, dairy farmers use approximately one million ha of grass, either as permanent grassland or in a ley-arable rotation. Permanent grassland is renovated if thought necessary by the farmer. Farmers have a wide variety of reasons for grassland renovation, predominantly related to herbage production and quality. Grassland renovation is economically only justified if the increased production and quality offsets the costs. At present, there is a lack of transparent criteria on which farmers can base decisions on grassland renovation. Grassland in ley-arable rotations is ploughed after one to five years to allow for arable cropping. On dairy farms with ley-arable rotations, maize (*Zea mays* L.) is the most widely used crop. In addition to the agronomic and economic aspects, grassland renovation can have a major environmental impact. Ploughing of grassland increases the release of soil nitrogen (N), which leads to an increased risk of nitrate losses to groundwater and surface water, and N_2O emissions.

The objectives of this paper are to (i) describe the current farming practices regarding grassland renovation, (ii) identify agronomic, environmental and economic consequences of current grassland renovation practices, and (iii) describe the state of the art in research concerning grassland renovation.

The available information on grassland renovation was gathered from literature and statistics. Based on these data, expert knowledge and simple models were used to estimate the environmental, agronomic and economic effects of grassland renovation.

1.1 General information

1.1.1 Nutrient policy in the Netherlands

From the 1950s onwards, dairy production systems in the Netherlands have shown a strong intensification and became increasingly dependent on imports of fertilisers and concentrates (e.g. Aarts *et al.*, 1992; Van der Meer, 1994). This intensification was economically justified in view of the high costs of land and labour, the low costs of fertilisers and concentrates, and the relatively high milk price. The amount of fertiliser N applied to grassland has increased from around 75 kg ha^{-1} year^{-1} in 1950 to approximately 300 kg ha^{-1} year^{-1} in the middle of the 1980s (Bussink & Oenema, 1998). The introduction of milk quota in the European Union (EU) in 1984 marked a turning point. The number of dairy cows reached a maximum of 2.55 million head in 1984 with a total milk production of 13 million t. Since then, the number of dairy cows has decreased to 1.5 million head with a total milk production of 11 million t.

Simultaneously, it was recognised that intensive dairy farming contributes to excessive nitrogen and phosphate (P_2O_5) losses to the environment. Therefore, from 1985 onwards, the Dutch government has introduced a series of regulations aimed to reduce the N and P_2O_5 losses (Henkens & Van Keulen, 2001). In 1998, the Mineral Accounting System (MINAS) was introduced. The MINAS balance is a 'farm-gate' balance, taking into account the N inputs such as fertilisers and feeds, and the N outputs through milk and animals. Nitrogen input through biological fixation and deposition does not have to be accounted for. By the year 2003 the allowed, levy-free, MINAS N surpluses are 140 kg ha^{-1} year^{-1} for grassland on dry sandy soils and 180 kg ha^{-1} year^{-1} for grassland on the other soil types.

In addition to the MINAS targets, the government has also imposed a variety of specific measures with which farmers have to comply. For instance, slurry has to be applied with techniques that minimise ammonia losses. The latest of these Directives, issued in January of 2002, prohibits the ploughing of grassland between 16 September and 31 January.

Furthermore, the EU Nitrate Directive sets the maximum amount of N from animal excreta at 170 kg ha^{-1}. The Dutch government has requested a derogation for grassland of 250 kg ha^{-1} (Willems *et al.*., 2000). The request is based on the favourable climatic conditions, the high N uptake of grass, and the additional Dutch nutrient policy. However, with respect to grassland renovation, the EU questions the uncertainty around nitrate losses towards ground and surface water.

1.1.2 Grassland in the present situation

The grassland area in the Netherlands decreases slowly by an average annual rate of 1%. In the year 2000, the total grassland area was 1.025.000 ha (CBS, 2000). Grassland covers approximately 25% of the total area, and can be found anywhere in the Netherlands (Figure 1). Approximately 44% of the total grassland area is situated on sandy soils, mainly in the South and East. Another 39% can be found on clay and loam soils. The remaining 17% is found on the peat soils in the North- and Midwest. Approximately 90% of the total grassland area is permanent grassland, but the proportion of temporary grassland is increasing. Temporary grassland in rotation with maize is mainly found on the relatively intensive dairy farms on dry sandy soils in the South and East. Additionally, temporary grassland is found in rotations with potatoes or flower bulbs. During the arable year of the rotation the land is rented by an arable farmer.

Perennial ryegrass (*Lolium perenne* L.) is the main grass species present in sown grasslands. The use of other species like timothy (*Phleum pratense* L.), meadow fescue (*Festuca pratensis* Hudson) and smooth-stalked meadowgrass (*Poa pratensis* L.) has decreased significantly since the early 1960s. Grasslands on clay, loam and sandy soils can generally be characterised as perennial ryegrass dominant swards. On peat soils, the proportion of perennial ryegrass is usually not higher than 30%. Other species like rough stalked meadowgrass (*Poa Trivialis* L.) are very common on peat soils.

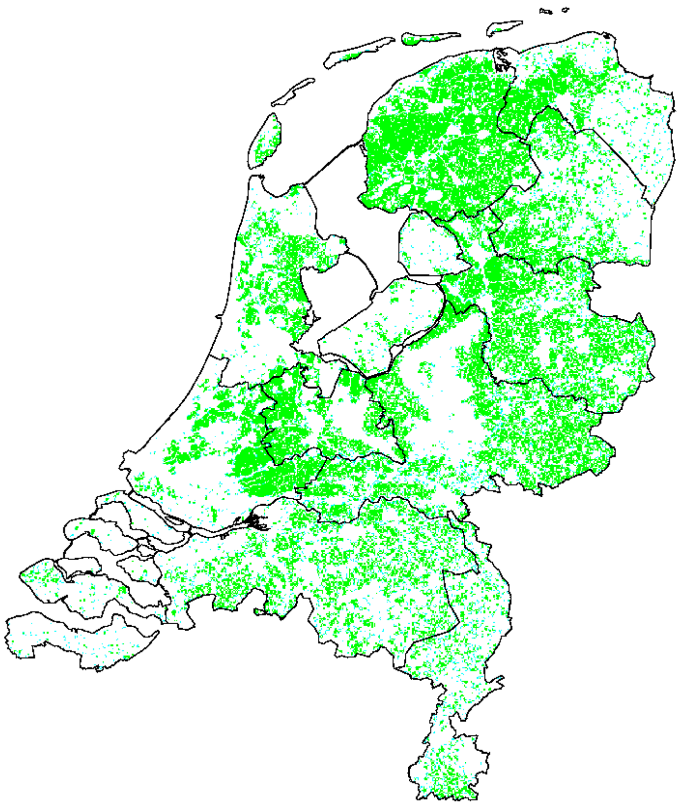

Figure 1. Grassland areas (green) in the Netherlands.

The Netherlands has some 28,000 dairy farms with an average of 53 dairy cows on 27 ha of grassland and 6 ha of fodder crops, mostly maize (Table 1). The farms in the North, mainly clay and peat, are relatively large farms. Farms on the sandy soils in the South and East are relatively small, but more intensive. The proportion of grassland on dairy farms in the North, West and South & East is 92, 84 and 77%, respectively.

Table 1. General characteristics of dairy farms in the Netherlands, in 1999 (LEI, 2002).

	North	West	South & East	Total
Dairy farms (n)	5,410	5,790	16,610	27,810
Area per farm (ha)	41.9	35.4	30.1	33.5
- grassland	37.2	30.7	22.2	26.9
- fodder crops	3.5	4.1	6.9	5.7
Dairy cows (n)	62.9	56.9	48.9	53.3
Milk quota (kg)	472,700	408,400	371,100	398,600
Milk quota (kg/ha)	11,282	11,537	12,329	11,906
Mineral fertiliser on grass (kg N/ha)	270	215	257	251

The differences between farms and their grassland management are much larger than suggested by the average figures in Table 1. For instance, 25% of the dairy farms produce less than 10,000 kg milk per ha, and 20% produce more than 15,000 kg milk per ha.

The dairy farms in the North and West have a stocking rate of 1.5 to 1.6 cows per ha, and produce approximately 11,500 kg milk per ha. The fertiliser N application is 270 kg ha^{-1}. Additionally, grassland on these farms will annually receive an estimated 35 t cattle slurry per ha, containing 85 kg inorganic N per ha, and a similar amount of inorganic N. N application is lower on the -mainly peat soils - in the West, due to the high soil nitrogen supply (SNS).

The farms on sandy soils in the South and East have an average stocking rate of 1.6 cows per ha and annually produce 12,300 kg milk per ha. The grassland annually receives 257 kg N ha^{-1} from fertiliser, plus an estimated 50 t cattle slurry per ha, containing 120 kg inorganic N per ha.

Grazing has always played an important role in Dutch dairy husbandry, as it is widely recognised as the cheapest way to convert grass into milk. On the major part of the grassland area, rotational grazing is integrated with cutting for silage in such a way that grazing at the right stage has first priority and that surpluses are cut for silage to support this.

Until the end of the 1960s, dairy cows usually grazed day and night, only interrupted by milking times. The introduction of the cubicle housing system with a separate milking parlour, made it possible to adopt a more flexible feeding management. Simultaneously, maize was introduced on the sandy soils in the South and East of the Netherlands. In thirty years the area grown with maize increased from approximately 6,000 ha to the present-day 220,000 ha. So gradually, more diverse grazing systems have developed throughout the country. The systems range from traditional day-and-night grazing, dominating on clay and peat soils in the North and West, to restricted or zero-grazing systems with supplementation of maize silage, dominating in the South and East. At present, it is estimated that the proportion of day-and-night grazing, day-only grazing and zero-grazing is 45%, 45% and 10%, respectively.

1.1.3 Grassland renovation

From the 1970s onwards, the area of renovated grassland has increased steadily. Presently, approximately 125.000 ha is renovated each year. However, there are considerable differences between years (Table 2), probably linked to weather conditions in certain years. For instance, the considerable area of sod-seeding in 1996 was caused by the severe winter of 1995/1996. In normal years, the area renovated by sod seeding is quite small. It is mainly practised on soil types on which tillage is difficult, such as heavy clay soils or peat soils with high groundwater tables.

In the ley-arable rotations, approximately 50% of the grassland is sown after a maize crop. In areas with a mix of specialised dairy and arable farms, grassland is often sown after a break with flower bulbs or potatoes.

Table 2. Annual grassland renovation (× 1000 ha) in the Netherlands (CBS, 2000).

Year	Permanent grassland		Ley-arable	Total
	Sod-seeding	Ploughing		
1990	14	61	52	127
1993	13	45	31	88
1996	50	59	44	153
1999	11	70	58	140

In 1999, 18% of the grassland area on sandy soils was ploughed and sown with grass (Table 3). On clay and peat soils, 10 and 3% of the grassland area was renovated, respectively. In other words, based on the data of 1999, grassland on sand, clay and peat soils is renovated on average every 5, 10 and 30 years, respectively. On sandy soils, two thirds of the renovated area was permanent grassland, whereas on clay soil two thirds of new grassland was sown following an arable crop.

Table 3. Grassland renovation in 1999 (× 1000 ha), in relation to soil type (CBS, 2000).

Soil type	Total grassland area	Renovated permanent grassland	Ley-Arable
Sand	450	55	29
Clay/Loam	400	12	26
Peat	175	3	3

1.1.4 Legislation

Only recently, the Dutch government announced that ploughing of grassland is prohibited between 16 September and 31 January. In common grassland farming this legislation generally does not conflict with the present practice. However, the bulb-growing sector opposes this legislation because it hampers the practice of autumn ploughing of grassland, followed by bulb planting.

1.2 Farmer's situation

1.2.1 Motivation for grassland renovation

In general, farmers decide to renew grassland if the performance of the existing sward, in terms of herbage production or quality, is lower than the potential performance. The lower performance is often caused by a single or a series of incidents.

Perennial ryegrass-dominated swards are relatively sensitive to periods of drought or frost. Considerable frost damage was observed in the winters of 1985/1986, 1986/1987 and 1995/1996.

Especially swards that had received high rates of N until late in the autumn were badly affected (Keuning *et al.*, 1988). A period of prolonged rainfall can have several negative effects on grassland swards. Direct damage during wet periods is caused by poaching of grazing livestock or by tyres of machinery. Indirect damage occurs through delayed silage cutting. The high grass yields lead to a slower aftermath regrowth and a lower sward density, thus creating opportunities for weed invasion.

High N application rates on sandy soils can cause urine scorching (Keuning *et al.*, 1988; Deenen, 1994) and a weaker root system (Sibma & Ennik, 1988). The use of incorrectly adjusted cutting equipment can also have detrimental effects on grass swards. Furthermore, pests, such as moles, mice or leather jackets, or fungal diseases may cause sward deterioration.

On clay and peat soils grassland renovation is also carried out if a field needs to be levelled. As the use of fertiliser N is gradually being reduced, a renewed interest in white clover may be expected, especially since nitrogen fixation by legumes is not included in the MINAS system so far. Grassland renovation creates a good opportunity to introduce white clover into the sward.

1.2.2 Criteria for grassland renovation

The present criteria for grassland renovation were developed in the 1970s and are only based on agronomic factors, of which sward composition is by far the most important. Grassland renovation is recommended if the proportion of perennial ryegrass is less than 50%. Furthermore, renovation is recommended if a sward contains more than 10% of couch grass (*Elymus repens* L.). On soils with high ground water tables the criteria are: (i) less than 50% perennial ryegrass and rough-stalked meadowgrass, or (ii) more than 15% couch grass.

If a field is uneven in such a way that it hampers good agricultural practice, it is recommended to level the field and establish a new sward.

1.2.3 Methods

At present, renovation of permanent grassland is normally carried out between mid-July and the end of September, although on sandy soils renovation in October occurs as well. This is usually indicated as 'autumn-sowing'. If the sward contains couch grass, it is recommended to kill off the old sward with glyphosate. However, the sward is often sprayed anyway because in farmers experience this makes tillage of the old sward easier. It is widely preferred to destroy the old sward with a rotatory cutter, followed by ploughing. Only if the soil does not allow tillage, such as heavy clay soil or peat soil, direct seeding into the old sward is recommended. The old sward is usually ploughed to a depth of 20 to 25 cm. Seed bed preparation is carried out shortly before sowing in such a way that there is a loose soil layer of approximately 2 to 3 cm on top of a firm soil.

In case a standard mixture of 100% perennial ryegrass is sown, the recommended amount of seed is 25 to 40 kg ha^{-1}, but farmers usually tend to be on the safe side and sow the maximum amount.

To make sure that the nutrient status of the newly sown sward is adequate, soil analysis is recommended, followed by application of the required nutrients, if necessary. Irrespective of the sowing time, a basic N application of 30 kg ha^{-1} is recommended (PR, 1998). Generally it is advised to be very cautious with the newly sown sward and if possible to graze lightly under good soil conditions for the first time.

1.2.4 Economics

Grassland renovation implies that costs are made for tillage, seeds, herbicides and pesticides (Table 4). The total costs depend on soil type, additional fertiliser needs and additional soil levelling. The basic costs for grassland renovation vary from € 557 ha^{-1} on peat soil to € 826 ha^{-1} on old clay soils. Additional fertiliser and soil levelling may increase the total costs to € 1392 ha^{-1}.

Table 4. Grassland renovation costs (€ ha^{-1}).

	Sand	Heavy clay	Light clay	Peat
Soil analysis	57	57	57	57
Herbicides				
Glyphosate	*27*	*27*	*27*	*27*
Other herbicides	*34*	*34*	*34*	*34*
Seeds	127	127	127	127
Fertilisers				
Basic application (P, K)	*84*	*45*	*45*	*36*
Additional application	*354*	*226*	*226*	
Contractor				
Spraying	*58*	*58*	*58*	*58*
Rotary cutting	*68*	*127*	*123*	*91*
Ploughing	*73*	*125*	*100*	
Seedbed preparation	*41*	*113*	*86*	*45*
Sowing	*54*	*113*	*60*	*82*
Levelling	*91*	*340*	*195*	*177*
Total				
Standard renovation	623	826	717	557
+ additional fertiliser	977	1052	943	557
+ additional fertiliser and levelling	1068	1392	1138	734

The benefits of grassland renovation are harder to quantify than the costs, mainly because there are only few studies in which renovated grassland has been compared with old grassland. Moreover, in most situations it is unclear what the production level of the old sward was before it was renovated. In order to determine whether grassland renovation is economically justified, the required production increase has been calculated for several soil types (Table 5). The calculations are based on the following presumptions:

- There is a direct loss of grassland production between the moment of ploughing and the first new cut, which is 25% for spring renovation and 12.5% for autumn renovation. Furthermore it is assumed that, compared to an existing sward, new grassland has a higher production in the first full production year of 8 to 15%, depending on soil type (peat > sand > clay). This annual extra production decreases to zero over the next four years (Figure 2).

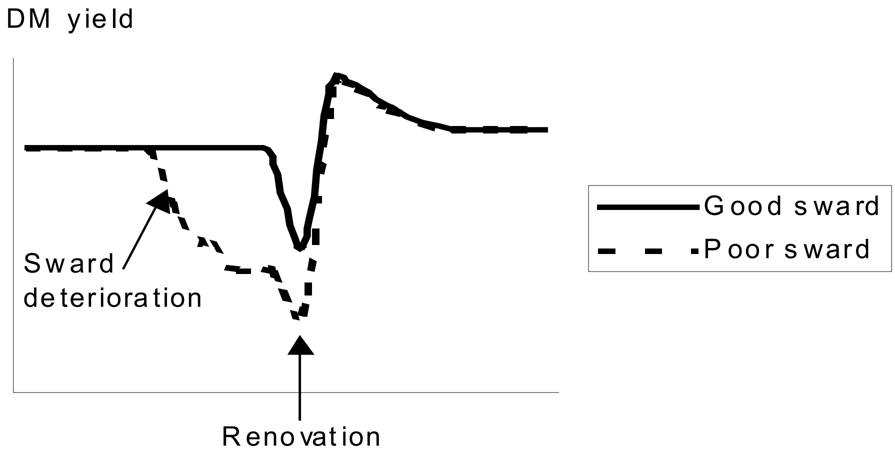

Figure 2. Assumed effect of grassland renovation on the DM yield.

- Due the use of new varieties, the potential yield of the new sward is higher than the potential yield of the old sward. This genetic improvement was estimated at 0.5% year^{-1} (Van Wijk & Reheul, 1991).
- The difference in net energy production between the new and old sward is higher than the difference in gross production, because of the higher feeding value (up to 7%) of the newly sown species and the lower grazing losses (up to 6%).
- The N losses are 100 kg ha^{-1} with spring-sowing and 300 kg ha^{-1} with autumn-sowing. As MINAS restricts the N input on a farm, this loss of N is valued as a loss of DM production, through the marginal N efficiency for grass production.
- An interest rate of 6%.

The calculations show that a substantial production increase is required to reach break-even, on top of the already assumed higher production. In other words, the production of the old sward must have deteriorated considerably, before grassland renovation is economically justified. On sand and clay soils a yield improvement of 23% is required, in case of a 5-year cycle. Longer depreciation periods of 10 or 15 years require a yield improvement of 13 and 10%, respectively. On peat soils, the required yield improvements are somewhat lower due to the lower costs.

It is remarkable that in farming practice grassland renovation is carried out more often than would be expected on the basis of these financial calculations. Clearly, farmers have a different view or take other factors into account, which have not been identified.

The economy of grass-maize rotations has been studied by Nijssen *et al.* (1996), based on results of field experiments on sandy soil. The yield of maize in rotation with grass was up to 7% higher than continuously grown maize. Due to the late harvest of maize, the new grass sward was established in spring next year. Consequently, the yield of first year grassland was 19% lower than the yield of the older swards. Together with the costs of grassland renovation, this means that the grass-maize rotation system was financially unattractive in comparison with a system of permanent grassland and continuous maize cropping. Under the present conditions, the MINAS regulations will also determine whether grass-maize rotations are used. De Haan (2001) concluded that on dry sandy soils grass-maize rotations are a good option to meet the MINAS targets, without negative effects on farm income.

Table 5. Required increase in grassland production to reach the economic breakeven point.

			Sand		Heavy clay		Light clay		Peat	
			Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
Renovation costs*	(€)		623	623	826	826	717	717	557	557
Extra yield new sward	(€)		30	-88	-14	-142	-14	-145	-33	-191
Nitrogen losses	(€)		84	251	84	251	84	251	84	251
Total costs	(€)		736	786	896	935	787	823	607	617
Interest	(€)		22	24	27	28	24	25	18	19
Annual depreciation	(€ yr^{-1})	5	169	181	206	215	181	189	140	142
over period of …. years		10	96	102	116	122	102	107	79	80
		15	71	76	87	90	76	80	59	60
Required yield increase	(kVEM yr^{-1})	5	2117	2260	2576	2688	2261	2365	1745	1774
over …. years		10	1197	1278	1456	1519	1278	1337	987	1002
		15	890	950	1083	1130	950	994	734	745
Required yield increase	(% yr^{-1})	5	23	25	25	26	22	23	18	18
over …. years		10	13	14	14	15	12	13	10	10
		15	10	10	11	11	9	10	8	8

* *See Table 4*

VEM = Net Energy for Lactation with kVEM = 1000 VEM

1.3 Research: state of the art

In the Netherlands, experimental studies into the effects of grassland renovation are scarce. There have been some studies that focussed on specific aspects, but an integrated study into the environmental, agronomic and economic consequences of grassland renovation has not been carried out yet.

1.3.1 Nutrient cycling

Ploughing of grassland has significant effects on nutrient processes in the soil (Figure 3). In a ploughed grassland soil there is increased mineralisation of plant material and soil organic matter. Therefore, the organic N content in the soil decreases after ploughing (Velthof *et al.*, 2000). In the case of grassland renovation, the organic N content will increase to the old level in several years. In the case of conversion to an arable situation, the organic N content steadily decreases until a certain equilibrium is reached. Vice versa, if arable land is converted into permanent grassland, the organic N content increases over the years. In ley-arable rotations, there is an alternation of increasing N contents in the grassland phase with decreasing N contents in the arable phase. In the ley-arable rotation as shown in Figure 3, it is assumed that the soil N content is more or less in equilibrium. However, there is no experimental support for this assumption. A relatively small upward or downward trend can have considerable effects on N losses.

It is evident that the increased N mineralisation increases the risk of N losses. The quantity and fate of mineralised N is related to the history of the old sward, the time of ploughing, the newly sown crop and the weather conditions. Model calculations indicate that in the first year, after ploughing a five-year old grass sward, the amount of soil organic N decreases by 100 to 300 kg ha^{-1} (Velthof *et al.*, 2000), indicating considerable mineralisation.

A literature review of Velthof & Oenema (2001) states that in the first 6 to 8 years, following grassland renovation, there is an N accumulation of 40 to 80 kg ha^{-1} in the stubble, 100 to 250 kg N ha^{-1} in the living roots and 100 to 200 kg ha^{-1} in plant and root litter. There is a higher N accumulation in clay soils than in sandy soils, due to the better protection of organic matter in clay soils. Soils with high ground-water tables accumulate more N than soils with low groundwater tables. Furthermore, the rate of N accumulation in grassland soils depends on the level of N input by fertiliser, slurry and biological fixation, and grassland management. However, due to lack of data, these effects are not quantified.

The longer a soil remains uncropped after ploughing the higher the risk of N losses. Generally, ploughing and sowing in spring or summer leads to a higher uptake of mineralised N than ploughing and sowing in autumn. Therefore, there is a lower risk of N losses with grassland renovation in spring or summer than in autumn.

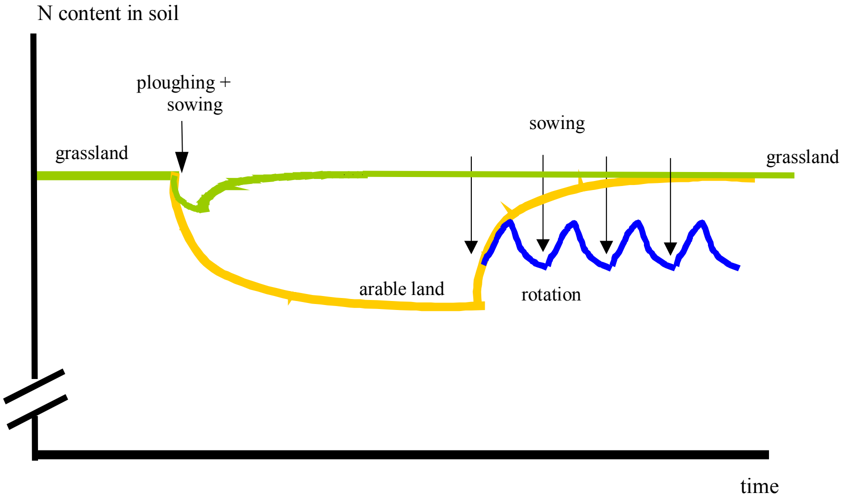

Figure 3. *Schematic representation of changes in the organic N content in the soil of permanent and temporary grassland and arable soils.*

In the Netherlands, there are hardly any direct measurements of N losses after ploughing grassland. Van Dijk (1997) compared the nitrate concentrations in drain water of newly sown grass/clover and maize on clay soil. Existing grass/clover fields were ploughed in January 1994. In April 1994, fields were sown with grass/clover or maize. During the winter of 1994/1995 the nitrate concentrations under grass/clover were always lower than 25 mg l^{-1}, whereas the nitrate concentrations under maize were between 50 and 200 mg l^{-1}. Nitrate concentrations under older existing grass/clover fields were between 25 and 50 mg l^{-1}.

Vellinga *et al.* (2002) calculated that ploughing of grasslands might contribute significantly to the emission of N_2O in the Netherlands. Recent measurements on clay soil indicate that, compared to permanent grassland, the N_2O emissions were 7 and 113 times higher after ploughing in spring or autumn, respectively (Van den Pol-Van Dasselaar; personal communication). The autumn measurements were carried out under extremely wet conditions.

On a dry sandy soil, Aarts *et al.* (2002) measured average nitrate concentrations of 62 mg l^{-1} under a grass-maize rotation, with lower leaching losses during the grass phase than during the maize phase. In the same period, the average nitrate concentration under permanent grassland was 69 mg l^{-1}.

Table 6. Estimates of soil N balances (kg ha[-1] year[-1]), changes in soil N and pathways of N losses, for four types of dairy farms in the Netherlands.

	Permanent grassland												Ley-arable rotation, dry sand						
	Sand			Clay				Peat					g	g	g	m	m	m	
	1 yr	2-6 yr	mean	1 yr	2-6 yr	7-10 yr	mean	1 yr	2-6 yr	7-10 yr	10-20 yr	mean	1 yr	2 yr	3 yr	1 yr	2 yr	3 yr	mean
Input																			
Animal excreta (excluding NH_3 losses) [1]	64	87	84	74	106	106	103	69	97	92	92	92	85	120	120	0	0	0	54
Cattle slurry (excluding NH_3 losses) [1]	135	189	180	99	140	140	135	81	135	126	126	126	240	240	240	0	90	105	153
Fertiliser	140	135	136	205	175	175	178	250	200	200	195	200	125	120	120	0	0	0	61
Deposition	40	40	40	35	35	35	35	30	30	30	30	30	49	49	49	49	49	49	49
Biological fixation	20	20	20	40	30	20	27	0	0	0	0	0	11	11	11	0	0	0	6
Total	399	471	459	453	485	475	478	430	462	448	443	448	510	540	540	49	139	154	322
Output																			
Removed crops	270	350	337	250	325	300	308	240	365	357	357	353	290	310	310	135	125	120	215
Surplus	129	121	123	203	160	175	171	190	97	91	86	95	220	230	230	-86	14	34	107
Change in soil organic	-125	25	0	-73	11	5	0	-310	-38	-52	-50	-60	100	70	70	-168	-48	-24	0
Leaching and denitrification losses	254	96	123	276	149	170	171	500	134	143	136	155	120	160	160	82	62	58	107
Denitrification (%)	55	55	55	70	70	70	70	85	85	85	85	85	40	40	40	25	25	25	33
N_2O -emission (%)	5	5	5	7	7	7	7	8	8	8	8	8	5	5	5	5	5	5	5
NO_3 - leaching groundwater (%)	38	38	38	3	3	3	3	0	0	0	0	0	55	55	55	70	70	70	62
NO_3 - leaching surface water (%)	2	2	2	20	20	20	20	7	7	7	7	7	0	0	0	0	0	0	0

[1] *Estimated ammonia losses: 10% for slurry and 8% for animal excreta during grazing*

[2] *g = grass ; m = maize*

Data from dairy farms in the 'Cows & Opportunities' project (Oenema *et al.*, 2001) and expert judgement were used to compile soil N balances for four situations on dairy farms (Table 6). It has to be emphasised that these data are only examples and do not intend to cover the whole picture of grassland renovation in the Netherlands.

The first year after ploughing permanent grassland, there is a high N mineralisation with a high risk of N losses. On the other hand, the establishment of a new sward immobilises N. The N losses can be minimised by ploughing and sowing in spring and by a fertiliser strategy that takes the high N mineralisation into account. Especially on peat soils, the N losses after ploughing can be considerable. The proportion of losses through denitrification increases from dry sandy soils to peat soils. In the ley-arable situation, it is assumed that the proportion of losses through denitrification will not be similar under grass and maize, due to a changed availability of degradable organic matter.

1.3.2 Soil quality

As discussed earlier, grassland ploughing has considerable effects on soil organic matter dynamics. Besides the mineralisation and immobilisation of nutrients, organic matter also affects the rooting capacity, the water holding capacity, the bearing capacity and the susceptibility to soil compaction. The effects of grassland renovation on soil quality and the subsequent effects on other factors are variable and usually hard to quantify (Table 7).

Newly sown grass roots deeper (Sibma & Ennik, 1988), thereby increasing the proportion of nutrient and water uptake from deeper soil layers. Especially on dry sandy soils, the increased water availability is an important advantage. In later years, roots, organic matter and nutrients concentrate in the 0-5 cm top layer.

On clay and peat soils the physical qualities of the soil, such as soil aggregate stability and bearing capacity, are generally negatively affected by grassland renovation.
Overall, grassland renovation of permanent grassland has positive effect on the soil quality of sandy and clay soils and a negative effect on the soil quality of peat soils. On dry sandy soils, ley-arable rotations have positive effects on the soil quality.

Table 7. The estimated effect of soil quality changes, due to grassland renovation.

Factor	Renovation of permanent grassland			Ley-arable	
	Sand	Peat	Clay	Dry sand	
				grass	arable
Nutrient supply	0/-	+	+	-	++
Water supply	+/++	0	0/+	+	++
Soil aggregate stability	0	---	--	0	0/+
Slaking susceptibility	0/-	0	0/--	0	0
Poaching susceptibility	0	---	--	0	0
Bearing capacity	0	--	-	0	+
Rooting depth	+	+	+	0	+
Air content	0/-	0/-	0/-	0	-/--
Levelling	+	+	+/++	0/+	+
Rooting capacity	++	0	+	++	+
General	+	--	+/0	+	++

1.3.3 Agronomic performance

In the Netherlands, there is no recent research into the effects of renovating botanically poorly valued grasslands. In recent experiments with comparisons between old and new grassland, the old grassland could be qualified as good grassland, not necessary to be renovated. Therefore it is difficult to quantify the performance of old and renovated grassland.

The yields of grass in a cutting experiment on sandy soil (Van Dijk *et al.*, 1996) were used to estimate the effects of grassland renovation on agronomic performance (Table 8). In these experiments, grass was sown in subsequent years, on a soil with a history of continuous maize cropping. Therefore, temporary grass swards of different ages could be compared. It is assumed that grass is sown in spring and that therefore the yield depression in the first year is 20%. Furthermore, it is assumed that there is a positive but varying effect in the second year, mainly based on experiments by Hopkins *et al.* (1990; 1995).

Table 8. Estimated effects of grassland renovation on DM and N yield, with annual N application rates of 280 kg ha^{-1} for sand, 245 kg ha^{-1} for clay and 240 kg ha^{-1} for peat.

	Year				100 % =… kg ha^{-1} year^{-1}
Sand	*1*	*2*	*3 - 6*	*mean*	
DM yield (%)	80	106-144	103	100-106	8430
N yield (%)	80	100-129	98	95-100	290
Clay	*1*	*2*	*3 - 10*	*mean*	
DM yield (%)	80	106-144	103	101-105	8400
N yield (%)	80	100-129	98	96-99	270
Peat	*1*	*2*	*3 - 20*	*mean*	
DM yield (%)	70	110	105	104	9346
N yield (%)	70	106	100	99	340

An annual yield increase of 0.5% may be expected through genetic improvement of grass varieties (Van Wijk & Reheul, 1991; Vellinga & Van Loo, 1994) . Next to yield improvements, the forage quality may be enhanced by grassland renovation. Observations in farming practice suggest a higher intake and lower grazing losses on newly sown swards. However, this can not be confirmed by experimental data.

1.3.4 Gaps in knowledge

As stated earlier, the major objective of further research should be to attain a complete picture of the environmental, agronomic and economic consequences of grassland renovation. More specifically, the main knowledge gaps are:

- Quantification of the effects of grassland renovation on N cycling and N losses in the plant-soil system, with respect to soil type, renovation strategy and crop management.
- Development of management strategies minimising the risks of N losses during grassland renovation'.
- Development of scientifically sound and practically applicable criteria to support farmers in decisions on grassland renovation.
- Further identification of farmers motives for grassland renovation.
- Quantification of the effect of grassland renovation on DM yield, herbage quality and animal performance.

Acknowledgements

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2. Ecological, environmental and economic aspects of grassland cultivation in Belgium

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2.1 General information

Grassland renovation or reseeding is necessary if the quality of the existing grassland leaves something to be desired. In Flanders, grassland is intensively used, particularly on dairy farms located on sandy soils. On these farms, grassland renovation is carried out frequently. The grassland used for beef cattle is less intensively managed and less frequently renovated. Also on loamy soils less reseeding is carried out because sward degeneration is more exceptional.

2.1.1 Grassland use in Belgium

In Flanders, the total agricultural area is 636,000 ha, in Wallonia this is 757,000 ha; a total of 1,393,000 ha. The most important type of agricultural land use is grassland (620,254 ha or 44.5%), followed by cereals, mainly winter wheat (276,734 ha). The remaining 35% is used to produce silage maize, industrial crops (e.g. sugar beet), potatoes and horticultural crops. In Flanders, the grassland area is 241,313 ha (38% of the total agricultural area in Flanders).

An average dairy farm in Belgium has about 38 ha of cultivated land, of which 67% is grassland and 33% is silage maize land. An average beef cattle farm has about 45 ha of cultivated land, 66% is grassland (NIS, 2001). The average stocking rate of a Flemish cattle farm is 3.16 LSU per ha of green fodder crops. In Wallonia this stocking rate is 2.49 LSU ha^{-1}. For Belgium as a whole, the stocking rate is 2.79 LSU ha^{-1}. Most dairy farmers in Belgium apply a grazing system keeping the middle between rotational and continuous grazing on three to four plots. This system is more flexible than pure continuous grazing and less flexible than rotational grazing. Beef cattle farms most often apply continuous grazing systems.

The average N-fertiliser use on Flemish dairy farms grassland is 265 kg N ha^{-1}. The average mowing percentage is about 150%. An average Flemish dairy farm has a milk production of 11,750 l ha^{-1}. The average milk production per cow is 5,731 l. The N-, P- and K-surpluses for the Flemish dairy farms are 295, 23 and 106 kg ha^{-1}, respectively (Michiels *et al.*, 1998; Verbruggen, 2001; Mullier *et al.*, 2001).

2.1.2 Grassland cultivation

The major part of the Belgian grassland is permanent (505,524 ha). The other part is temporary grassland (in particular Italian ryegrass). The area of red clover and lucerne is negligible. Figure 1 illustrates the evolution of the fodder crop areas in Belgium in the past century. There was a large decrease in temporary grassland since the 70's as result of the introduction of silage maize. In the early 90's the area of temporary grassland was increasing again, caused by the CAP legislation. Recently, the difference between permanent and temporary grassland in statistics is more or less artificial: to maximise the arable crop support more grassland is reported as temporary grassland instead of permanent grassland.

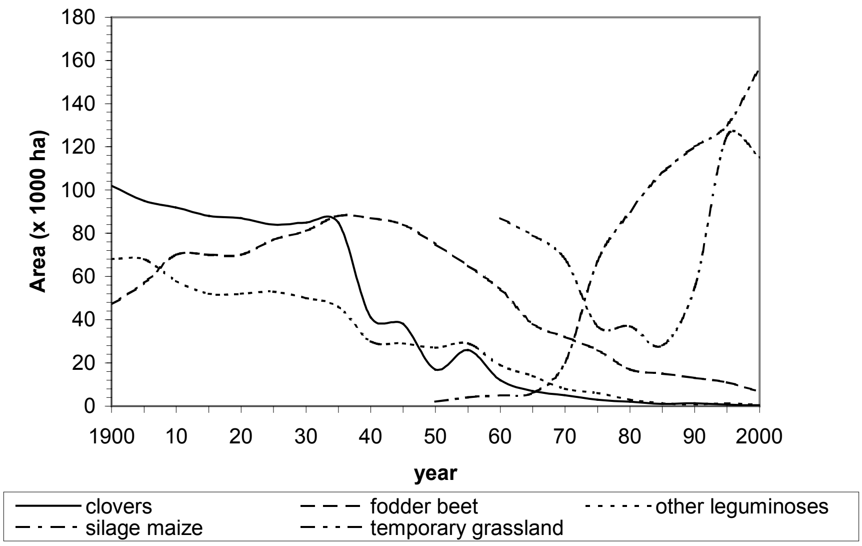

Figure 1. *Area of fodder crops in Belgium (1900–2000).*

On many dairy farms on sandy soils, Italian ryegrass is sown following the September-October silage maize harvest. One spring cut is taken before ploughing and seeding maize again. This strategy allows farmers to apply 25% more fertiliser (Flemish Manure legislation, Ministry of the Flemish Community, 1991-2000) and hence to place more of their manure production on their own fields (except for farms in nitrate-vulnerable zones).

Exact figures of grassland reseeding in Belgium are not directly available. Only an estimate can be made, based on the grass seed sales for agricultural purposes. Considering these sales and assuming an average use of 45 kg of grass seed per ha, the area of grassland reseeding in Belgium should be about 43,200 ha each year, corresponding with about 7% of the grassland area. This would also mean that the average age of grasslands is about 14 years.

2.1.3 Legislation

In Belgium there is no specific legislation with respect to grassland cultivation. Only when the farmer has entered into a nature management agreement on a grassland field (in order to enhance the botanical diversity or the meadow bird populations) he is not allowed to plough the grassland or to reseed it during the period of the agreement.

2.2 Farmer's situation

2.2.1 Causes of grassland renovation

The general view is that under Belgian conditions grassland should contain a high proportion of perennial ryegrass (*Lolium perenne* L.) which is a highly productive grass species with a high nutritive value and which is very suitable for grazing. Especially in Flanders farmers prefer and are encouraged to keep a high percentage of perennial ryegrass in their swards. In Wallonia, where grassland is used more extensively, other grasses like timothy (*Phleum pratense*), meadow fescue (*Festuca pratensis*) and smooth stalked meadow grass (*Poa pratensis*) are also considered valuable under the applied regimes of lower N-fertiliser use.

On 'good' soils, particularly the loamy soils, grasslands can keep a good botanical composition for a long period: 20 years or more are not exceptional. In these regions it is not usual to renew the grassland very frequently. Here we find old grasslands that still have a good botanical composition.

On sandy soils farmers are more used to renovate their grassland. Especially on soils with compacted layers in the underground, it 'is difficult to maintain a desired botanical composition following years with abnormal weather conditions (drought). On such soils the invasion of annual meadow grass (*Poa annua*) or couch grass (*Elymus Repens*), both low quality grasses, is often a problem. Under dry conditions there can be a quick shift from a good sward to a less productive and less palatable one. This is also the reason to renovate those grasslands more frequently. Quite often incorrect management is also a major reason of sward deterioration and hence the need for grassland renovation. Too late cutting or grazing or driving with heavy machinery (during harvest or when animal slurry is brought on) under wet conditions can degenerate the sward quality. In some cases winter killing of e.g. perennial ryegrass can also cause negative changes in botanical composition. On the heavy clay soils, slurry injection under dry conditions can also contribute partly to sward deterioration. Abundant presence of weeds, like dandelion (*Taraxacum officinale*), docks (*Rumex obtusifolius*) and chickweed (*Stellaria media*) can be a major reason for quality of a grass field to drop. However, these weeds can be controlled chemically.

2.2.2 Criteria for grassland renovation

Farmers make the decision to renovate or reseed if the quality of the grassland leaves something to be desired. This is the case when they consider production to be insufficient or when the animals apparently leave large amounts of grass after grazing. A change in the botanical composition of the sward quite often is the main reason for this conception of lower quantity and quality.
This implies that real criteria do not exist; the decision to renovate is more induced by subjective parameters.

Objective criteria exist but are not commonly used. An example: according to Behaeghe (1991), renovation should be considered seriously when couch grass presence is more than 15%,.

2.2.3 Methods and time of grassland renovation

In Belgium grassland renovation is usually carried out during August and September. In this period, the weather conditions are somewhat better than in spring (drought risk). The new grass plants can develop rather quickly and the competition of weeds is less than in spring. Another advantage of reseeding in August or September is that the yield losses are lower compared to spring reseeding.

Reseeding of grassland or sowing of grass after another crop can be carried out after thorough tillage of the soil, but also through direct sowing into the old sward (sod-sowing), with or without minimum tillage. The latter method is regularly used in Wallonia on grassland in strongly hilled areas (larger erosion risk). In Flanders the use of a special rotary tiller system, destroying small strips of the sward in which clover is seeded, is in an experimental stage.

The common way to reseed Flemish grasslands is the following. The sward is always destroyed chemically (glyphosate). This is considered necessary to avoid that old sward rests regrow, resulting in a less successful renewing of the grassland. After this killing of the vegetation, the old sward is destroyed with a rotary tiller. This enhances the breakdown of the old vegetation after ploughing and prevents that the old sward is brought up again during cultivation. Ploughing loosens the soil and buries the topsoil, which mostly contains the seeds of undesired species of grasses and weeds. The usual ploughing depth is about 25 cm. Sometimes levelling is carried out with special levelling machinery (laser controlled). Seedbed preparation is usually carried out with a rotary harrow (on loamy or clay soils) or, on sandy soils, with a cultivator, possibly combined with a packer. Seedbed preparation and sowing can be executed in one operation, e.g. with a heavy tractor provided with a powered rotary harrow and a sowing machine. The grass can be sown with a fertiliser broadcaster. On mixed farms with arable crops a grain-sowing machine is often used. In that case, because of the higher row distance, broad sowing coulters are sometimes used or criss-cross sowing is applied. Some farmers obtain good results with a grain-sowing machine without pipes, which simply drops the seed on the surface (on top of the seedbed with a fine weeding harrow after that).

2.2.4 Economic costs/benefits of grassland renovation

Grassland renovation is expensive. It should only be carried out if the botanical composition is insufficient. Grassland improvement is only justified if the costs involved are repaid by the subsequent higher yields, better forage quality and possibly by easier working. However, making a cost-benefit analysis is not easy.

The costs of grassland renovation in Belgium show a high variability. Farms with less fertile soils have to renew their meadow frequently (every 3 to 4 years) due to the fast botanical degradation of the sward. Other farms with good loamy soils don't have to keep to this frequency. Every 6 years is a good average of renewing the sod. So the costs of reseeding should be spread over these six years. The costs of grassland renovation under average Belgian conditions are shown in Table 1. The total costs are estimated at € 365 per ha. In a scheme of renovation every six years this means a yearly cost of 365/6 = € 61 per ha. In Belgium it is estimated that 100 kg dry matter of grass has a value of about € 8.63 (Coomans *et al.*, 2000). This means that new grassland should yield an extra 700 kg DM ha^{-1} year^{-1} (€ 61) to repay for the renovation costs. This means that the new grassland should produce 5 to 7% more than the 'old' one.

Table 1. Costs of grassland renovation (€ ha^{-1})

Treatment	Costs
Chemical destruction	55
Rotary tilling	56
Ploughing	63
Seedbed preparation	50
Sowing	41
Seeds	100
Total costs	365

2.3 Research: results in Belgium

2.3.1 Grassland cultivation and the environment

Specialised dairy farms in Belgium have only two crops in their rotations: grass and silage maize. Maize cropping in monoculture causes major problems and is not compatible with sustainability principles

(Nevens & Reheul, 2001). On the other hand, grassland renovation in autumn is not always environmentally friendly because of of the high nitrogen release, not sufficiently taken up by the reseeded grass and hence prone to overwinter leaching. Introduction of an arable crop for at least one year could deal with these problems. Recently, the Flemish Landbouwcentrum Voedergewassen of the Belgian Ministry of Small and Medium Enterprises and Agriculture studied the consequences of grassland cultivation on subsequent silage maize at 3 different locations (Mertens *et al.*, 2001 and Mertens & Bries, 2002). The grass sward was destroyed at 2 different times in spring (January and April) with a rotary tiller before maize was sown. Two N-fertiliser rates were applied to the silage maize (Table 2).

Table 2. Survey of the treatments.

Treatment	Time of sward destruction	Nitrogen fertilisation
1	January	0
2	January	150 kg N ha^{-1}
3	April	0
4	April	150 kg N ha^{-1}

After the maize was harvested, residual soil nitrate-N (0–90 cm) was determined. The results are given in Table 3.

Table 3. Survey of nitrate (kg N ha^{-1}) in the soil profile (0-90 cm).

Treatment	NO_3-N (kg N ha^{-1})		
	Location 1	Location 2	Location 3
1	49.9	87.1	197.8
2	240.6	195.3	312.7
3	61.5	32.6	188.5
4	136.7	246.3	233.3

In Flanders, manure legislation considers an amount of residual soil nitrate-N exceeding 90 kg ha^{-1} (0-90 cm, measured between 1 October and 15 November) as environmentally harmful, i.e. resulting in surface or groundwater nitrate concentrations exceeding 50 mg l^{-1}. The experimental results show that it is only possible to remain under this limit when no fertiliser N was applied to the silage maize following the ploughed grassland. In the case of location 3 (wet soil) it 'is impossible, also without any fertiliser, to stay below the 90 kg limit.
We add that the silage maize dry matter yields were similar, with or without fertiliser N application.

From 1990 to 1998, a study was done into the N-release from ploughed 3-year-old grazed grasslands in the subsequent three seasons of forage crops on a sandy loam soil in Melle (Nevens & Reheul, 2002a). Silage maize in the ley-arable rotation outyielded continuous maize on permanent arable plots by 85, 21 and 2% at mineral N fertilisation rates of 0, 75 and 180 kg N ha^{-1}, respectively. This decreasing yield effect with increasing N fertilisation indicated that the ley-arable rotation effect was mainly a N-contribution effect. The N release was highest during the first year; it decreased during the second and third year following grassland ploughing. Economically optimum N-fertilisation rates for silage maize in these years were 2, 139 and 154 kg N ha^{-1}, respectively. Simultaneously, on permanent arable plots this was 152, 191 and 183 kg N ha^{-1}, respectively. This resulted in comparable yields (19.75 t DM ha^{-1} year^{-1}) but with a possible saving of 231 kg of mineral N fertiliser ha^{-1} in a 3-year silage maize period following the ploughed leys compared with continuous silage maize. The N-uptake by silage maize on temporary arable plots following grassland was higher than on permanent arable plots, owing to the higher yields but also to an increased N concentration in the crop on the temporary arable plots. Starting the arable forage crop sequence with fodder beet following grassland ploughing and adjusting the N fertilisation to the enhanced N release minimised the risks of high amounts of residual soil N and hence N leaching losses.

2.3.2 Grassland renovation and dry matter production

An experiment was carried out to determine the quality and the dry matter yield of a 1-, 2-, 3-, 4- and 5-year old pasture under rotational grazing conditions (DM yields were determined by cutting strips, De Vliegher *et al.*, 2002). During five consecutive years (1996–2000) the same grass or grass/white clover mixture was sown. From the results of the past 5 years it is clear that the dry matter yield on reseeded grassland was lower than on well-established older (6 years) grassland. The main causes were the yield losses during the autumn of sowing and the lower yields during the first growing season, when the new pasture is still establishing. The 'old' pasture remained in optimal condition, qualitatively as well as botanically, and hence kept yielding highly. On average, during their first growing season, reseeded ryegrass or grass/clover mixtures yielded 12 and 27%, respectively, less compared to the 'permanent' 1996 pasture. Woldring (1975) and Mott & Ernst (1984) came to the same conclusion that reseeding does not automatically increase the yield when the botanical composition of the old sward is of good quality.

Table 4. Influence of reseeding grass and grass/white clover mixtures on the total net dry matter yield under grazing conditions during the period 1997-2001.

Treatment/harvest year	1997	1998	1999	2000	2001[3)]
Ryegrass					
Sowing 1996 (09 Sept.)	100	100	100	100	100
Sowing 1997 (07 Oct.)	94[1)]	**90**[2)]	102	99	100
Sowing 1998 (29 Sept.)		96[1)]	**92**[2)]	85	92
Sowing 1999 (26 Sept.)			91[1)]	**82**[2)]	91
Sowing 2000 (05 Sept.)				88[1)]	**88**[2)]
Kg DM.ha^{-1} at 100	9537	10326	9961	13418	11275
Grass and white clover					
Sowing 1996 (09 Sept.)	100	100	100	100	100
Sowing 1997 (07 Oct.)	98[1)]	**54**[2)]	85	111	101
Sowing 1998 (29 Sept.)		95[1)]	**73**[2)]	105	105
Sowing 1999 (26 Sept.)			94[1)]	**76**[2)]	72
Sowing 2000(05 Sept.)				86[1)]	**88**[2)]
Kg DM.ha^{-1} at 100	8416	10491	11588	11817	9806

1) *net yield of sowing 1996 up to the sowing date*
2) *net yield in the first year after sowing*
3) *net yield until 1 October*

Permanent grassland was compared with three-year temporary leys alternating with three-year periods of arable forage crops during 31 years (1969 to 1999) on a trial (M66.1) in Melle (Nevens &Reheul, 2002b). The average feed energy yields of both types of grasslands, 75.1 and 73.3 GJ NEL ha^{-1}, respectively, were not significantly different. Possible preconditions for the lasting high production level of the 31-year-old, never reseeded permanent pasture were the high fertilisation level (200 to 350 kg N ha^{-1} $year^{-1}$) and the preservation of a fairly good botanical composition. The temporary grasslands produced as much as the permanent grassland without the necessity to apply higher amounts of fertiliser N during their three-year lifetime.

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3. Grassland cultivation in Denmark

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Abstract

Intensive grassland in Denmark is part of a crop rotation scheme. Typical grassland is established in spring in a cover crop, lasts for 2-3 years, is managed with a combination of cutting and grazing and has a high content of white clover. Through legislation there are restrictions on N-application for all types of grassland. There are no restrictions on P-application.

There is a considerable build-up of N in pastures and after ploughing of grassland the mineralisation of N often exceeds the need of the subsequent arable crop. In a crop rotation N-leaching was highest in the second winter following ploughing and lowest in 1st grass/clover year. It is also shown, however, that good management practice, as spring-ploughing, reduced N-fertilisation and undersown catch crop, can reduce N-leaching to an acceptable level. Further improvement of N-utilisation therefore seems to be more dependent of improvements in the pasture phase than in the arable phase of the crop rotation.

Dry matter production decreased with the age of the grassland, and under cutting conditions the decrease was higher than under grazing conditions. The grass became less stemmy with age of the sward and the content of crude protein seemed to increase. The content of white clover could be maintained at least in the first three years.

3.1 General information

3.1.1 Intensity

Historically, Danish intensive grassland has been part of a crop rotation scheme. This is mainly due to the high positive residual effects on the following grain crop in terms of both nitrogen and diseases and to a high grass yield in newly established swards. Furthermore, most agricultural land in Denmark is lowland with a relatively low content of clay, and cultivation is therefore always possible. Intensive grassland is characterised by being established in spring with a cover crop, lasting only two to three years in a crop rotation scheme and having a high content of white clover.

Typical crop rotations on dairy farms are shown in Table 1. The main difference between conventional and organic crop rotations is the higher amount of grass/clover in the organic system, which is due to an optimisation of N-fixation. Crop rotation including a number of forage crops gives a dynamic production, which can be modified relatively quickly when changes in production and economy occur.

After many years with high levels of N-fertiliser and pure grass the re-introduction of grass/white clover mixtures has been highly successful in Denmark. This is mainly due to a change in farmers' understanding of the advantages of clover and the environmental problems in general. Furthermore, the Danish method, especially short-lasting grasslands and irrigation, has facilitated the re-introduction of clover . Other important reasons are limitations on N-fertiliser use and the use of tetraploid perennial ryegrass. Furthermore, for many farmers a good establishment of grass/clover has a higher priority than the yield of the cover crop, which among other things means that the cover crop is allocated a lower fertiliser rate.

Table 1. Typical crop rotations on dairy farms, conventional and organic.

Year	Conventional	Organic
1	Spring barley for whole-crop with undersown grass/clover	Spring barley and pea for whole-crop or grain with undersown grass/clover
2	Grass/clover – year 1	Grass/clover – year 1
3	Grass/clover – year 2	Grass/clover – year 2
4	Spring barley for grain with undersown Italian ryegrass	Grass/clover – year 3
5	Winter wheat or spring barley for grain with undersown Italian ryegrass	Winter wheat or spring barley for grain with undersown Italian ryegrass
6	Fodder beet or maize	

In the past, there were areas of grass for cutting and areas for grazing, and grazing management consisted of continuous grazing with a sward height of 6-7 cm. The reasons for using this method were, *inter alia,* irrigation of a large part of the grassland and a limited herd size. Nowadays the cost of silage production is very high, and therefore areas for cutting only are limited, and management is nearly always a combination of cutting and grazing. Typically, 3-4 paddocks are continuously grazed, and in each paddock rest periods used for cutting are included. This method aims to reduce rejected grass areas and diseases, especially lung worms. Over the last few years, due to increasing farm size and herd size, an increasing number of farms have changed to indoor feeding only and no grazing. This is further pushed by the use of milking robots. This tendency is expected to increase in the future, and therefore more grassland will be used for silage only in the future.

Nearly all grassland is sown with seed mixtures, of which approximately 90% are mixtures recommended by the Danish Institute of Agricultural Sciences and The Danish Agricultural Advisory Centre (Søegaard *et al.*, 2000). A widely used seed mixture for intensively grazed pastures is 21 kg perennial ryegrass (7 kg medium tetraploid, 6 kg late diploid and 8 kg late tetraploid) and 5 kg white clover ha^{-1}. Red clover used to be a common grassland species for cutting in grassland lasting for only two years. Nowadays red clover is used together with white clover on organic farms but not on conventional farms. However, on large conventional farms without grazing the use of red clover on cutting areas is expected to increase.

The yield of forage on dairy farms is calculated as net yield. Losses during wilting and ensiling are deducted. The yield of grassland is measured on 26 private dairy farms every year. Grassland is used for cutting and grazing, and on average 66% was grazed in 1998. The average annual net yield in 1998 was 7.4 t DM ha^{-1} (Studielandbrug, 1998). The intake during grazing depends largely on supplementation and pasture management, and the intake is calculated as energy in milk yield minus energy in supplements and corrected for energy utilisation by the cow. The intake during grazing varied between 6.9 and 14.9 kg DM cow^{-1} day^{-1}, with an average of 10.5 kg DM cow^{-1} day^{-1}. Danish Holsteins, which constitute approximately 70% of all milking cows, yielded 7,619 kg milk in 1998, with average constituents of fat and protein of 4.2% and 3.4% for the country as a whole (Nygaard, 1999). The average life stock density for all cattle farms is 1.5 LSU per ha. The net yield of grassland (intake under grazing plus silage) is relatively low compared to other forage crops, when grazing is a part of the management (Figure 1). On the other hand, the costs per net feed unit are lowest on grassland, which is mainly due to low costs under grazing.

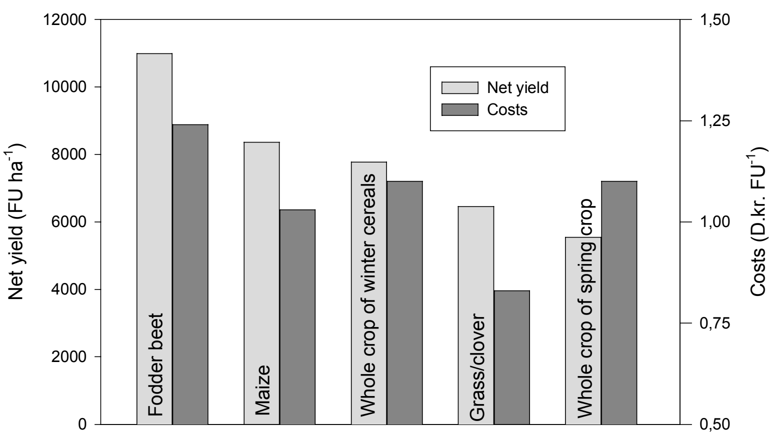

Figure 1. *The net yields in Scandinavian feed units (FU) and the costs (Danish kr. per FU) of different forage crops on 26 dairy farms, mean of 1997-1999. Losses under harvest, wilting, ensiling and storage are deducted. Grass/clover has been used for both grazing and cutting. The costs are excluding EU hectare subsidies for maize and whole-crop. Roughly, one FU corresponds to 1 kg barley (Studielandbrug, 1999).*

3.1.2 Land use

Agricultural production in Denmark is relatively intensive as regards both management and land use. The land used for agricultural production amounts to 62% of the total area (Table 2). Danish agriculture can be divided into three main production categories: arable, pig and cattle farming. The cattle are used mainly for milk production and more than 80% are dairy cows (Table 2) even though the number of beef cattle is on the increase. Furthermore, there is limited sheep production, primarily based on small herds. Forage is produced on only 22% of the agricultural land, with grass being the most important forage crop (Table 2).

The area of permanent grass (including semi-permanent) for agricultural utilisation, which comprises only 6% of the total agricultural area, has declined drastically since the 1970s. Permanent grass is mainly found on low lying wet soils or dry hilly areas and the utilisation is mostly extensive and of marginal agricultural interest. Even though landscape and nature value, including an increase of biodiversity, have high priority with the authorities, subsidies for improvements are negligible and have limited effect on farmers' income.

The dairy farms are primarily placed in Jutland, especially on coarse sandy soils (<5% clay) or clayey sandy soils (<15% clay), making irrigation of grassland necessary if a high production level has to be maintained. The national precipitation in the summer half-year is 347 mm on a 30-year average, whereas the potential evapotranspiration is 475 mm (Danmarks Statistik, 1998). However, there are great year-to-year variations because of coastal climate. Grassland has a high priority as regards irrigation and the authorities accept 100-120 mm as a yearly mean for irrigation. Primarily, groundwater is applied for irrigation.

Table 2. Area of land, area of forage crops, and number of farms and animals in 2000.

	1000 ha		Number
Total land area in Denmark	4,301	Total number of farms	59,288
Total agricultural land	2,644	Dairy farms	11,162
Grass and clover for seed	81	Organic dairy farms	882
Total land with forage crops	587		
Permanent grass (incl. semi-permanent)	160	Total number of cows	762,000
Grassland in crop rotation	238	Milking cows	640,000
Maize for silage	48	Suckle cows	122,000
Fodder beet	23	Total number of sheep	143,000
Whole-crop of barley, wheat, pea etc.	118		

Danmarks Statistik (2000)

3.1.3 Reducing environmental pollution via restrictions

For many years Danish agriculture has moved towards more sustainability and since the beginning of the 1980s, environmental effects have been in focus. This first resulted in claims for improved utilisation of animal manure with focus on storage capacity and time of application. However, these steps were not sufficient to reach the desired reduction of N-leaching and the reduced application of mineral fertilisers was unsatisfactory. The authorities therefore introduced maximum standards for N-application in 1994 in order to reduce the use of mineral fertilisers and improve the utilisation of animal manure. In 1999 the standards for maximum nitrogen application were reduced to 90% of the economic optimum.

In Table 3 the N-standards of the most important grassland crops are shown. After the establishing year the N-standards are not influenced by the age of the grassland. The N-standards are the maximum amounts of N from mineral fertiliser plus animal manure. N in cattle manure is expected to have a utilisation of 60%, and therefore only 60% of total-N in cattle manure are included in the calculations. In pastures N-excretion from grazing animals has to be included in the N-account. Therefore, the maximum amount of N-application is lower than that shown in Table 3. By way of example, in pastures with more than 50% clover it will not be possible to apply any N, because the N-standard corresponds approximately to N-excretion.

As mentioned earlier, one of the advantages of short-lasting grassland is the residual effect on the following crop. In the N-standards the residual effect of grass/clover is estimated at approximately 60 kg N ha^{-1} for the first year, when compared to the residual effects after a grain crop (Table 3).

The Danish N-standards are the most important restrictions even though Danish agriculture also has to comply with the EU Nitrate Directive. This Directive especially affects the average number of animals per ha. From 1 August 2002 the maximum LSU will be 1.7 per ha. If over 70% of the cultivated area are grassland or fodder beet the maximum is 2.3 LSU.

Nitrogen has been the focus of discussions about environmental pollution in Denmark. However, the P-surplus and the consequences of this are now being debated but so far no fixed standards have been set for nutrients other than N. There are only normative standards for P and K.

On grasslands slurry must only be applied in the period 1 February - 1 October, and for farm manure in the period 1 February - 20 October. There are no claims for grazing at conventional farms, whereas at organic farming the cattle must graze at least 150 days per year.

Table 3. Standards for maximum N-application at a certain annual net yield (yield-standard) are shown for some crops on two soil types in 2002. In total there are 99 N-standards for different agricultural crops on three different soil types and for sandy soil there are standards for both irrigated and unirrigated land.

	Sandy soil – unirrigated		Clay soil	
	N-standard kg N ha^{-1}	Yield-standard t DM ha^{-1}	N-standard kg N ha^{-1}	Yield-standard t DM ha^{-1}
Grass crop				
Permanent pure grass	27-140 [1)]	0-4	27-140 [1]	0-4
Established short lasting:				
Pure grass	285	6.5	303	7.5
Grass/clover, < 50% clover	204	6.0	213	6.5
Grass/clover, > 50% clover	55	5.0	70	6.5
Establishing year after harvest of cover grain-crop:				
Pure grass	53	1.0	53	1.0
Grass/clover	33	1.0	33	1.0
Spring barley				
Cereal as previous crop	119	4.1[2)]	121	5.9 [2]
Grass/clover as pervious crop	56	4.1[2)]	58	5.9 [2]

[1] *Depending of yield level, Plantedirektoratet (2001/2002)*
[2] *Grain yield*

3.2 Farmer's situation

3.2.1 & 3.2.2 The need and criteria for grassland cultivation

The great positive residual effects on subsequent crops, concerning fertility, diseases and weeds, together with a high productivity in new grassland have been the main reasons for the long tradition of placing grasslands in crop rotations. These residual effects are still the main reason together with the historically tradition, whereas economic reasons do not seem to be of importance. There is a generally accepted view that clover will disappear from older grassland, more than three years, and cultivation is therefore necessary to maintain a high clover content. However, lack of results concerning longer lasting grasslands means that farmers do not have the knowledge for changing the rotation system.

3.2.3 Method for grassland cultivation

Grass, with and without clover, is always spring-sown together with a cover crop, which is typically spring barley or pea. Ploughing before sowing is often carried out in spring. The seeds are sown two times, first the cover crop to a greater depth (5-6 cm) and second the grass only to 1-2 cm. The cover crop is harvested either as a green crop, as a whole crop or as a grain crop. Grass growth thereafter depends very much on the harvest time of the cover crop. The use in the autumn in the establishing year is typically grazing with dairy cows, because the palatability is higher than in the older pastures. For those farmers who take care of clover establishment, N-application is reduced both to the cover crop and to the grass after harvest of cover crop. Grazing in autumn also improves clover establishment.

3.3 Research: state of the art

3.3.1 Nutrient cycling

It is currently recognised that a considerable build-up of N takes place in grazed grassland and that ploughing of grassland is followed by a large increase in the N-mineralisation which often exceeds the need of the subsequent arable crop. This was illustrated in an organic dairy crop rotation during 1994-1998 (Figure 2; Eriksen *et al.*, 1999). Nitrate leaching was highest in the second winter (after winter wheat) following ploughing, and leaching losses were lowest in 1st year grass/clover.

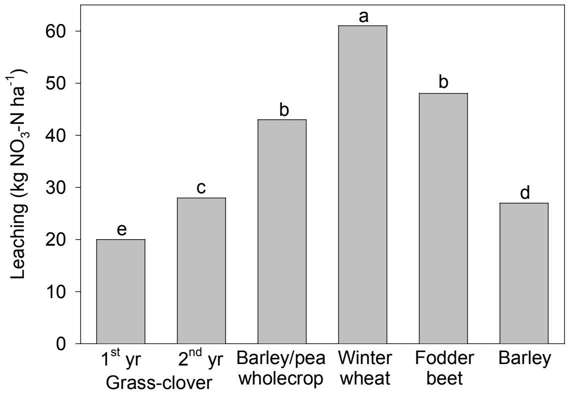

Figure 2. Nitrate leaching from an organic dairy crop rotation on loamy sand as average of 1994-1998. Bars with the same letter are not significantly different (P<0.05)

However, it is also recognised that the applied management practices both in the grassland and the arable phase very much influence the fate of nitrogen in the dairy crop rotation. Factors affecting the build-up of N in grazed grassland, such as fertilisation, feeding of dairy cows, stocking density, time of grazing and botanical composition of the sward also affect N-use efficiency. Similarly, management in the ploughing out phase regarding time of ploughing, choice of crop sequence, fertilisation etc. will affect possibilities for efficient utilisation. These issues have been studied under Danish conditions and the results are summarised below in two sections focussing on the arable and the grassland phase of the mixed crop rotation.

The arable phase

The effect on nitrate leaching of postponing grassland cultivation from early to late autumn or spring in combination with spring or winter cereals was studied on two sandy soils (Djurhuus & Olsen, 1997). The results showed that winter wheat did not have the potential for taking up the mineralised N in autumn after early autumn ploughing and least leaching was found when ploughing was postponed until spring. It was found that after ploughing out in late autumn or spring the soil should be cropped in the following autumn and winter. In agreement with this it was found in the crop rotation shown in Figure 2 that replacing winter wheat with oats followed by a ryegrass catch crop reduced nitrate leaching from the crop rotation (Askegaard & Eriksen, in preparation).

The residual effects of six different temporary grassland fields on yield and nitrate leaching were investigated in three years after ploughing. The grassland fields were unfertilised grass/clover and fertilised ryegrass subject to cutting or continuous grazing by dairy cows with two levels of N in feed supplements (Eriksen, 2001; Eriksen & Søegaard, 2000). The N balance during the grassland period was calculated from measured data during this period and indirect estimates. During the pasture phase of the rotation (1994-1996) the N surplus increased considerably in the order: cut – grazed low N – grazed high N as a consequence of increasing N deposition in dung and urine. The N-surplus was higher in grazed ryegrass compared with grass/clover due to higher fertiliser inputs and lower N-intake under grazing. In the first year after ploughing there was sufficient residual effect of the grazed grassland to obviate the need for supplementary fertiliser (Figure 3), but in the following years gradually more fertiliser N was required to obtain optimal yields.

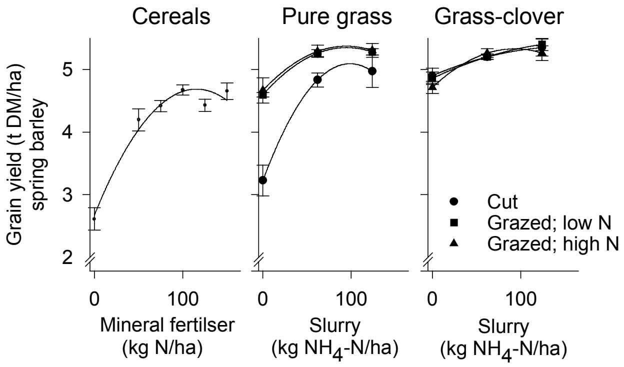

Figure 3. *Yields of barley grain on loamy sand in year 1 following ploughing of grassland (pure grass and grass/clover) compared to similar yields following a cereal history. Low and high N refers to 140 and 300 g N cow^{-1} d^{-1} in supplements to dairy cows (corresponding to appr. 230 and 320 kg N ha^{-1} year^{-1} excreted in the field). Error bars: ±SE.*

The experiment was carried out under 'good management practices': the swards were ploughed in spring and ryegrass was undersown in the cereals as a catch crop. This helped minimising nitrate leaching (Figure 4) and annual mean nitrate concentrations in unfertilised plots were 33, 15 and 9 mg NO_3 l^{-1} in the three successive years, which is well below the EU Drinking Water Directive upper limit of 50 mg NO_3 l^{-1}. Application of cattle slurry to cereals influenced nitrate leaching more than the history of the grassland and caused the annual mean nitrate concentrations to exceed the EU limit in most cases.

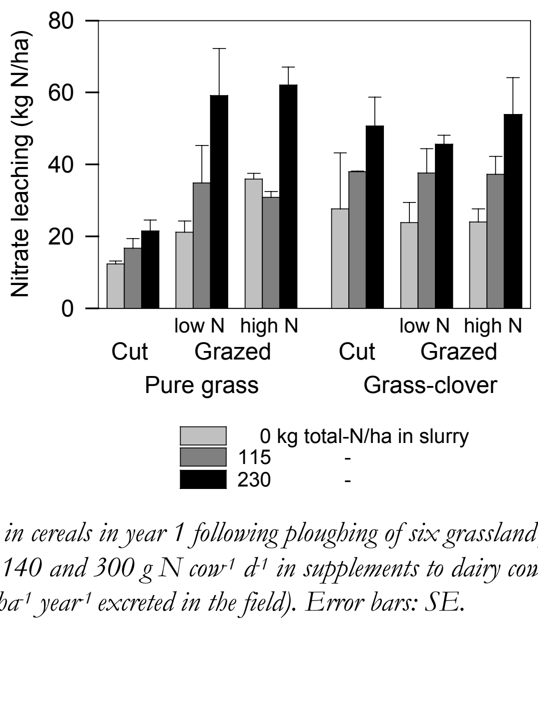

Figure 4. *Nitrate leaching in cereals in year 1 following ploughing of six grassland fields on loamy sand. Low and high N refers to 140 and 300 g N cow^{-1} d^{-1} in supplements to dairy cows (corresponding to appr. 230 and 320 kg N ha^{-1} year^{-1} excreted in the field). Error bars: SE.*

Overall, leaching losses from grass and grass-clover mixtures were similar. For grazed grassland, the sum of leaching losses and N-uptake in crops in the three years did not match the huge N-surplus. The most extreme was grazed high-N grass, where almost 1000 kg N ha^{-1} accumulated over three years and only about 400 kg ha^{-1} was recovered in leaching and N-uptake after cultivation. A major part of the difference was probably already lost as nitrate leaching and gaseous emissions before ploughing of the grassland. In the present study the ammonia losses from urine and dung during grazing was estimated at 17-25 kg N ha^{-1} $year^{-1}$, depending on the N-level in feed (Petersen *et al.,* 1998).

The grassland phase

In 2000-2001 the simultaneous nitrate leaching from newly established swards, swards grazed for 1 and 7 years and swards cut for 7 years was investigated (Eriksen & Vinther, 2002). Both type of grassland and age influenced nitrate leaching significantly with a strong interaction between the two (Figure 5). Thus, nitrate leaching was very low for grass/clover (average 6 kg N ha^{-1}) and similar for all swards in contrast to pure ryegrass where nitrate leaching increased dramatically with increasing sward age. Following the establishment of pure ryegrass undersown in barley, nitrate leaching was only 6 kg ha^{-1} increasing to an average of 17 and 60 kg in swards grazed 1 and 7 years, respectively. Apparently, the build-up of soil N has reached equilibrium at 7 years of grazing resulting in a larger part of the fertiliser input being lost through leaching.

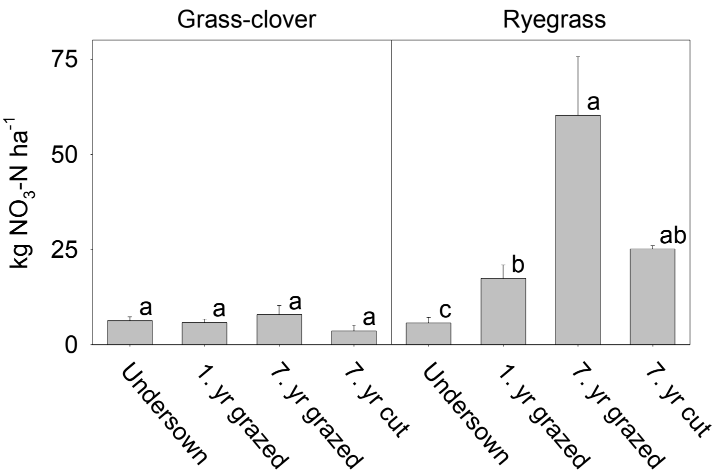

Figure 5. *Nitrate leaching from grasslands on loamy sand of different composition, management and age. The swards were established by undersowing in barley. Bars with the same letter are not significantly different within each grass type (P<0.05). Error bars: SE.*

Modelling

Attempts have been made to model mineralisation and nitrate leaching following grassland cultivation using the deterministic DAISY model, but it proved difficult because the input of organic matter and N was not well defined in time and space (Jensen *et al.*, 1999). Another approach was the development of an empirical model based on investigations of drainage from pipe drains during 1973-1989 and suction cup measurements during 1988-1993 (Simmelsgaard, 1998; Simmelsgaard & Djurhuus, 1998). The weakness of the empirical model is that the nitrate leaching estimates only reflect the management practices of the data collection period. Recognising the importance of management practices as described above and the changes towards 'good management practices' in Danish farming, the use of the empirical models seems unsuitable for predicting effects of grassland cultivation.

Conclusions

The huge N-pool in grazed grassland mineralised upon cultivation presents a potential environmental hazard but when using good management practices such as spring ploughing and catch crops, the release of N can be controlled and nitrate concentrations in leachates may be kept below the EU Drinking Water Directive upper limit of 50 mg l^{-1}. The total leaching loss from a dairy rotation depends on the utilisation of the N accumulated in grassland. Leaching losses are minimised by including residual effects in the fertiliser requirements of crops following the ploughing of grasslands. The history of the grazed grassland (grass/clover or pure ryegrass, low or high N levels in feed) did not affect residual effects and nitrate leaching after cultivation. Presumably, huge differences in N-input during the grassland phase of the crop rotation were equalised by substantial but variable N losses during grazing. Possibilities for further improvement of the utilisation of grassland N following cultivation are limited when the current knowledge has been implemented. If the N use efficiency of dairy farming systems is to be further improved the utilisation of N in the pasture phase must be considered regarding the frequency of pastures in the rotations and management during grazing.

3.3.2 Soil quality

Grassland has a positive effect on other crops in the rotation. Thus, higher yield potentials have been found following cultivation of grassland than following cereals (Eriksen, 2001). This non-nitrogen effect was attributed to improved soil structure and better resistance against fungal diseases.

In a crop rotation experiment it was found that the organic C content of the soil increased by 10% over a six-year period in crop rotations having 2-3 years of grassland compared to rotations without grassland (Søegaard, 1988). This increase was not followed by a similar increase in soil organic N.

Direct measurements of the CO_2 flux showed that cultivation of grassland was followed by a total emission of 2.6 t C ha^{-1} during the first 3 months after cultivation compared to only 1.4 t/ha emitted from the untilled soil (Eriksen & Jensen, 2001).

3.3.3 Yield and herbage quality

Yield

Under cutting conditions, yield decreases from year to year after cultivation. Under Danish conditions this is primarily shown in a large experiment on nine experimental sites, at different N-levels, with and without irrigation and with and without mixing with white clover. On average the yield decreased by 13% from year 1 to year 2 and by 23% from year 2 to year 3. After five years the yield was reduced by about 60% with the highest reduction under unirrigated conditions (Table 4).

Under grazing conditions the yield reduction over years is considered to be lower than under cutting conditions. However, this hypothesis is not well-founded, but it is supported by a single large-scale grazing experiment with dairy cows where the calculated net yield in pure grass only decreased by 3% and 6% from year 1 to 2 and year 2 to 3 respectively (Table 5). In grass/clover the establishment of white clover (year 0) was insufficient and therefore the yield in year 1 was low. On commercial Danish farms it is not possible to calculate intake/net yield per ha on individual paddocks, because of the above-mentioned typical grazing management, where cutting and grazing are mixed on more pastures.

Table 4. Cutting experiment at nine research stations over two five-year periods, from 1st to 5th harvest year. The mean yields in year 1 are shown and the yield reduction over the five years.

	Pure grass		Grass/white clover			
	(300 N)		(150 N)		(0 N)	
Irrigation	+	÷	+	÷	+	÷
Annual yield (kg DM ha^{-1})	10,018	9,814	10,800	10,036	8,428	8,349
Yield reduction over five years (%)	58	67	57	69	51	69

Gregersen (1980)

Table 5. Net yield (kg DM ha^{-1}) in an experiment with continuous grazing of dairy cows. The net yield is calculated intake, estimated from the theoretical energy requirement for milk production, weight gain and maintenance minus the indoor energy consumption.

	Pure grass	Grass/white clover
Year	300 N	0 N
1	8,908	6,293
2	8,613	8,265
3	8,071	7,971

Søegaard et al. (2001)

Herbage quality

Even though management has an important influence on herbage quality, the age of the sward seems to have some general effect on quality. When lasting 2-3 years maintaining white clover content seems not to be a problem. On eight commercial farms the white clover content was on average relatively high in year 1-3 (Table 6), but the content varied very much from pasture to pasture. On average the clover content was lower in the autumn of the establishing year (year 0) and in spring in year 1; thereafter the clover content was relatively constant (Table 6). However, a prior condition seems to be a low N-application. The total N-application, slurry and fertiliser, on the eight farms was 0-176 kg N ha^{-1} year^{-1}. With the purpose to improve clover establishment, the undersown grass/clover was not fertilised after harvest of the cover crop in the establishing year on these eight farms (Table 6).

The pastures are normally topped to reduce the amount of grass stem and the amount of rejected area. However, grass seems to be less stemmy with age (Table 6 and 7). The reason can both be an effect of age and an effect of changes in grass composition. From the beginning the grass is a mixture of medium and late perennial ryegrass, both di- and tetraploid.

Digestibility of organic matter (IVOMD) seems not to be affected by age of the sward. Even though there were significant differences (Table 6 and 7) the reasons seem more to be small differences in management.

Table 6. Registrations on eight commercial dairy farms in pastures grazed continuously by dairy cows.

	Spring			Autumn		
	Year 1	Year 2	Year 3	Year 0	Year 1	Year 2
Botanical composition						
White clover (% of DM)	21.2	26.6	30.4	19.4	28.1	28.8
Weed (% of DM)	2.0	1.3	0.5	2.9	0.6	2.7
Dead plant material (% of DM)	9.1	7.3	5.1	10.2	11.9	9.9
Grass stem (% of grass-DM)	31.9^{a}	22.5^{ab}	18.8^{b}	6.5	8.8	10.7
Herbage quality						
Crude protein (% of DM)	19.6	21.1	20.6	22.0	24.2	24.4
K (% of DM)	2.8^{a}	2.3^{b}	2.2^{b}	3.3^{a}	2.6^{c}	2.9^{b}
IVOMD (% of OM)	79.6	81.1	81.2	77.1^{a}	75.3^{b}	76.2^{ab}
N-application (kg N ha^{-1})[1)]	70	78	67	0	17	19
Number of pastures	15	7	5	17	15	11

[1)] N-application in the previous two months, Søegaard (2002)
Different letters indicates significant differences within period (P<0.05)

It was expected that the high N-surplus in pastures would affect the content of crude protein and N-response over the years. The hypothesis was that the content of crude protein would increase and the response to N-application would decrease over the years. Concerning crude protein this has only partly been found. On the commercial farms there was only a tendency of increasing over years (Table 6). Residual effects of earlier grassland also seem to have influenced the content of crude protein. In the grazing experiment (Table 7), however, the hypothesis was confirmed. Concerning effects of N-application it is examined in an ongoing experiment. Effects of different N-levels on pastures with different age (year 1 and 2) are examined on four commercial farms under cutting and grazing conditions. Preliminary results are ambiguous. Both the same and a smaller N-effect has been found on production in year 2 compared to year 1 (Søegaard, personal communication).

Table 7. Content of crude protein and digestibility of organic matter as a mean throughout the season and content of grass stem of grass dry matter in spring (May-June) year 1-3 after cultivation. Experiment with dairy cows grazing continuously on pure grass (300 N) and grass/white clover (0 N), respectively.

Year	Pure grass	Grass/clover	Pure grass	Grass/clover	Pure grass	Grass/clover
	Crude protein (% of DM)		IVOMD		Grass stem (% of grass-DM)	
1	21.9^{b}	22.2^{c}	81.8^{b}	80.8^{b}	24.0^{a}	30.0^{a}
2	21.6^{b}	26.2^{b}	79.8^{c}	81.5^{ab}	18.6^{b}	20.2^{b}
3	25.0^{a}	29.6^{a}	83.1^{a}	82.1^{a}	2.2^{c}	3.1^{c}

Different letters indicate significant differences within sward type (P<0.05), Søegaard et al. (2001)

The composition of minerals changed over years on the commercial farms (Table 6). K content decreased and as a consequence the Na, Mg and Ca content increased (data not shown). This effect is probably a result of K-output being higher than K-input and reflects more the K-fertilisation strategy than the effect of age.

Conclusions

Dry matter production decreases with grassland age. Under cutting conditions the decrease is higher than under grazing conditions. The grass becomes less stemmy with the age of the sward and the crude protein content seems to increase. The white clover content can be maintained in the first three years.

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4. Grassland resowing and grass-arable crop rotation in France: agricultural and environmental issues

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4.1 General information on grassland

Rural areas represent more than 2/3 of the total area of France and are the main collector of rainwater, which flows to rivers or drains through soils to water tables. Thus they have a major effect on water quality because rainwater may cause pollution while leaching through soils or running off from surface or subsurface. Figure 1 presents the distribution of the total area, and Figure 2 the distribution of grassland in France.

- Animal husbandry uses slightly more than 60% the of agricultural area (AA), and 49% AA as grassland,
- these areas are generally in high-rainfall zones,
- they generate large amounts of organic matter,
- moreover, animal husbandry is often associated with surface water or shallow water tables. Water quality can therefore change quickly, positive as well as negative (few years to a decade).

Animal husbandry often is a source of nitrogen pollution, but grassland areas also plays a very important role in water production and quality conservation through their high capacity to remove nitrogen from the soils and the large amount of rainfall water that drains through grassland soils. In most of the animal husbandry areas (Ouest of France, mountains) the water balance exceeds 5000 m^3 ha^{-1} yr^{-1}, compared to the national mean of 3000 m^3 ha^{-1} yr^{-1}. Thus, taking into account the areas used by animal farming and the corresponding climatic conditions, animal husbandry is thus « responsible » for 40% of the water resources.

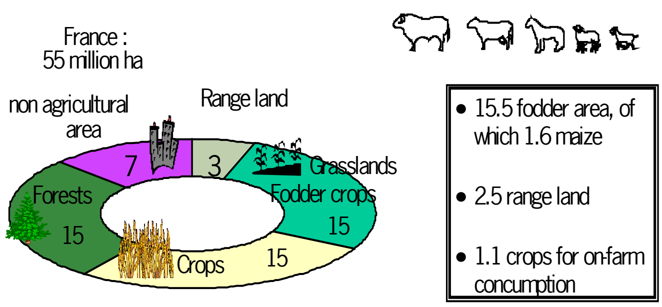


Figure 1. Animal husbandry occupies more than 60% Utilised Agricultural Area (expressed in million hectares).

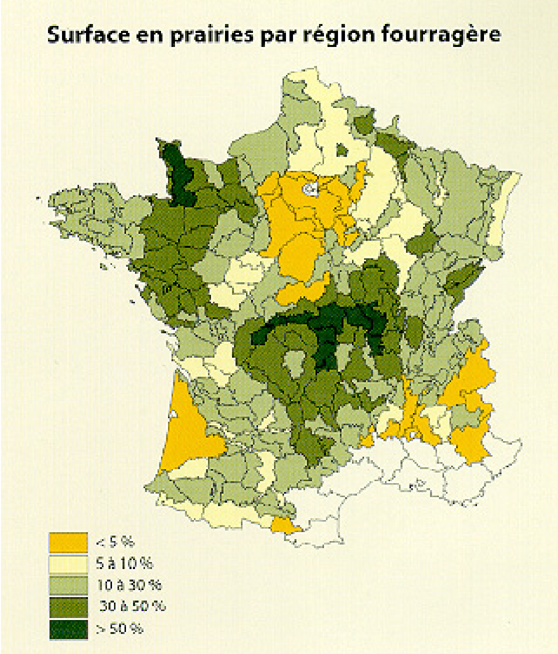


Figure 2. Distribution of grassland zones.

4.1.1 Intensity of grassland use on commercial farms

The mean apparent N surplus at farm level is around 200 kg ha^{-1} yr^{-1} for conventional dairy farms (1.8 to 2.2 LSU ha^{-1}, 7-8000 l milk cow^{-1}, 40% maize, 40% grass, 20% other crops) (Figure 3). It is lower when the same system is optimised (130-150 kg N ha^{-1} yr^{-1}) and on less intensive farms, i.e. low-input sustainable systems and organic systems, with variation between regions due to the level of intensity and the natural pedo-climatic potential for grass growth. In optimised dairy farm systems, the minimum N excess seems to be about 80-100 kg ha^{-1} yr^{-1}.

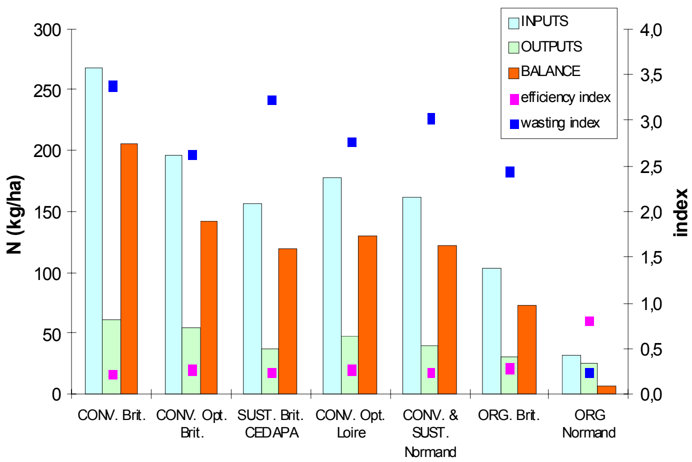


Figure 3. Apparent N balance at farm scale on dairy farms of Western France.

The N balance in grazed pastures varies between –10 and +360 kg N ha^{-1} yr^{-1} for fertilisation of 0 and 400 kg N ha^{-1} yr^{-1}, respectively. Milk production corresponds to an export of 60 to 110 kg N ha^{-1} yr^{-1} , depending on the individual production level and on the stocking rate, whereas that in meat production is around 20 kg N ha^{-1} yr^{-1}. Cow excreta were estimated at 65 to 130 kg N cow^{-1} yr^{-1}, depending on the animal fodder regime (CORPEN, 1999).

Some statistical relationship was observed between N leaching and the N balance at field level (Farruggia *et al.*, 1997); the stocking rate seems to be a good indicator of leaching risks (Simon *et al.*, 1997, Vertès *et al.*, 1997, Laurent *et al.*, 2000, Vertès *et al.*, 2002). The large variability indicates the importance of two factors: soil and climatic conditions (drainage, nitrification) and management (level and distribution of fertilisers, grazing management).

According to a recent study (AGRESTE 2000, Table 2), the mean input of N chemical fertilisers on fertilised temporary grassland (TG) varies from 40 (Provence) to 115-120 (West) and 150 (North) kg.ha^{-1}.yr^{-1}, with the lower inputs on permanent grassland (50 to 110). Organic fertiliser input on fertilised pastures varies from 100 (Provence) to 130-150 kg ha^{-1} (West and North), with the lower inputs on permanent grasslands (50 to 120 kg N ha^{-1}) . At the national French level, mean mineral fertilisation on temporary and permanent grassland is 83 and 43 kg N ha^{-1} yr^{-1} (98 and 64 for fertilised pastures), respectively, and the mean organic N input is 25 and 19 kg N ha^{-1} yr^{-1}, respectively (130 and 104 for fertilised grassland). These data are an indication of the huge variability in N input.

Table 1 summarises the main characteristics of animal husbandry regions (based on Recensement Général de l'Agriculture 1988). Only the mean mineral fertilisation levels are considered. Some slurry, manure or compost is also used in many situations but amounts and N content are usually not known (80% of the cattle farms produce and use manure or compost, 20% have slurry, which they rather use for maize). In regions with intensive pig or poultry husbandry, farmers are encouraged to use slurry instead of mineral fertilisers.

Table 1. Main characteristics of animal husbandry regions (based on RGA 1988).

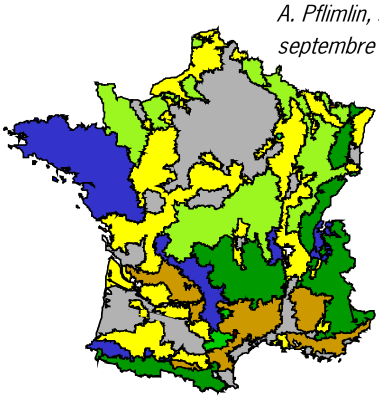
	Farm size ha AA	Animal type	LSU/ha	Maize % AA	PP* % AA	Mean fertiliser kg N/ha/year	Soil type	% AA	% livestock
Crops/animals	70-100	Milk and beef cattle	<1	4%	24%	60-80	Calcareous	24%	20%
Fodder crops/ soilless animals	25-40	Milk and beef cattle + pigs and poultry	1.5 – 2 or more	15-50%	40%	80-100 or more	Free draining soils on granite or schistes	17%	> 30%
Permanent pastures	40-50 or 70-100	Milk and suckling cows, sheep	1 - 1.5 or <1	0-10%	63%	60-80	Heavy/poorly drained soils	20%	30%
Permanent swards – crops	30-40 + range lan	Sheep and goats	<1	2%	57%	45-60	Karstic soils	4%	3%
Mountains	20-50 + mountain pastures	Milk and beef cattle, sheep and goats	<1	1%	>80%	45-60	High slopes	8%	12%

** = permanent pastures*

To conclude, Rouquette & Pflimlin (1995) distinguish five zones for the distribution of animal husbandry farms (Figure 4):

1. regions for crops and animal husbandry with moderate production potential: 24% of AA and 20% of the livestock;
2. intensive animal husbandry regions with dominant forage crops: 17% of AA and more than 30% of the livestock (Brittany, Pays de Loire);
3. herbage regions (North, Normandie, north of Massif Central and Lorraine): 20% of AA and 30% of herbivore livestock;
4. mediterranean zones: 4% of AA and 4% of the livestock;
5. wet mountain and high mountain areas: 8% of AA and 12% of the herbivores.

carte adaptée de J.-L. Rouquette,
A. Pflimlin, J. Caillette, Institut de l'Elevage,
septembre 1995.



		NO_3^-	P	Pest.	Bactério. et mo
Crops/animal indoors		++	-	++	-
Fodder crops + animal indoors		+++	++	++	+/++
Permanent grassland areas	-	+	- +/	(+)	+
Range + crops		+	-	-	++
Mountains		+	+	-	+++

Figure 4. Agricultural pollution in breeding areas of France.

4.1.2 Intensity of grassland cultivation

Table 2 presents the main characteristics of grassland distribution and types in the regions. The ever-grass areas (GA) represent more than 2/3 of the total agricultural area (AA) in four mountain regions dominated by dairy or beef production (Limousin, Auvergne, Jura, Alpes), between 1/3 and 2/3 of the agricultural area for ten regions, including the intensive dairy farms of Western France with grass (PP) or grass/maize fodder systems (TP), the last eight regions being dominated by crops. Temporary grassland and grassland cultivation are more important in Western France: Brittany, Pays de Loire.

In intensive dairy farms of Western France (Brittany, Pays de Loire, Aquitaine), fodder systems are based on grass and maize. The main reason for grassland cultivation is to get land for maize. In Brittany, where maize constitutes 30 to 50% of the fodder area, the mean duration of grass leys is 4 to 7 years. In south-western areas, where maize is more important, the mean duration of grassland is 3-5 years. In Pays de Loire, temporary grasslands last 4-10 years. Table 3 shows that in Brittany 10-13% of the grassland is destroyed per year with small variations between optimised fodder systems. In the other regions with animal husbandry, grasslands are mainly permanent.

Table 2. Distribution of grassland areas in France: type and annual mean yields (from RGA 2000 and AGRESTE 2000). Swards are part of the ever-grass areas (GA); PA consist in pure forage legumes, PP is permanent grasslands and TP temporary grasslands.

	GA (% AA)	Swards (% AA)	PP (% AA)	PP (q/ha)	TP (% AA)	TP (q/ha)	PA (% AA)
ALSACE	25	2	22	55-65	1		0
AQUITAINE	34	4	19	55-65	10	75-85	1
AUVERGNE	78	5	58	55-65	15	30-75	1
BASSE-NORMANDIE	57	0	49	65-75	8	85-105	1
BOURGOGNE	46	1	40	45-55	6	30-75	1
BRETAGNE	40	1	10	65-75	**29**	85-105	0
CENTRE	17	0	10	45-55	7	30-75	1
CHAMPAGNE-ARDENNE	20	0	19	45-55	1	30-75	5
CORSE	85	65	18		2		2
FRANCHE-COMTE	67	4	50	45-55	13	30-75	1
HAUTE-NORMANDIE	29	1	27	65-75	2	85-105	1
ILE-DE-France	3	0	3	45-55	0		1
LANGUEDOC-ROUSSILLON	43	29	10	45-55	4		2
LIMOUSIN	85	6	55	45-55	**24**	30-75	0
LORRAINE	44	1	40	65-75	3	75-85	0
MIDI-PYRENEES	43	8	20	55-65	15	75-85	4
NORD – PAS-DE-CALAIS	22	0	21	65-75	1	85-105	0
PAYS DE LA LOIRE	46	1	22	55-65	**23**	75-85	1
PICARDIE	12	0	12	65-75	0	85-105	0
POITOU-CHARENTES	25	1	11	55-65	13	30-75	2
PROVENCE-ALPES-COTE AZUR	48	37	9	45-55	2	75-85	4
RHONE-ALPES	58	15	35	45-55	8	75-85	2
France métropolitaine	**40 (43)**	**5 (6)**	**25 (30)**	**59**	**10 (8)**	**81**	**1 (2)**

Table 3. Field distribution (A) and risk indicators (B) as function of fodder systems (Le Gall, pers. comm.). MFA is main fodder area.

		Silo opened all year	Silo closed in spring	100 days pure grazing	150 days pure grazing	Full grass
A: field distribution						
	Livestock units/ha	1.87	1.84	1.83	1.81	1.73
	Grass (ha)	10.2	12.7	15.7	18.5	26.3
	Maize (ha)	14.2	12.0	9.2	6.5	0.0
	Cereals (ha)	8.0	7.7	8.3	8.3	8.7
	Fallow (ha)	2.7	2.6	1.9	1.6	0.0
	MFA/AA (%)	70	71	71	72	75
	Maize/MFA (%)	58	48	37	26	0
	Permanent pasture/ grassland (%)	76	81	62	50	22
B: risk indicators						
on maize	% maize after grassland cultivation (1)	24%	26%	43%	71%	50% (2)
on maize	Effect of grassland destruction (kg N/ha)	38	29	49	80	50
on maize	% bare soils	56%	64%	55%	90%	50%
on UAA	% maize after grassland. cultiv.(1)	10%	9%	11%	13%	12% (2)
on UAA	Effect of grassland destruction (kg N/ha)	23	18	24	28	13
on UAA	% bare soils	23%	22%	24%	24%	12%

(1) equal % grassland cultivation
(2) maize is replaced by wheat or barley

4.1.3 Legislation with respect to grassland cultivation

The Nitrate Directive (2001) implies special care concerning grassland cultivation in sensitive areas (selection of catchments important for water resources and drainage areas). It is i) recommended not to destroy grassland aged more than 3 years, ii) forbidden to destroy grass closer than 10 m to stream or river and obligation to leave or make a permanent grass buffer strip along rivers, iii) forbidden to fertilise the crop following grassland destruction and it is highly recommended to sow a catch crop under maize to take up the mineral nitrogen remaining after maize harvest (no bare soils during winter). These prescriptions are valid for all other situations as advice.

It must be remembered that the usual practice (at least in Brittany) was to spread animal manure before destruction, which was mixed with soil when tilled, then to sow maize with 'starter' fertiliser N–P, and finally fertilise with slurry. Advisors are now discouraging these practices.

4.2 Farmer's situation

4.2.1 What causes the need for grassland cultivation?

An inventory is now in progress at Service Central des Enquètes et Etudes Statistiques, which will for the first time precisely record the management of temporary grassland in crop rotations (age, type, ..) and analyse the criteria farmers use for their decisions. Three types of reasons were considered until now to account for grassland destruction: i) the need of land for maize or wheat in the intensive systems based on grass and maize silage, ii) the high positive residual effects on the following crops, and iii) in both extensive and intensive systems, the observed decrease of grassland productivity with time (weeds, soil compaction and trampling damage (Cluzeau *et al.*, 1992), low persistency of clover in mixed swards…).

Usually farmers destroy the pastures that are far from the animal housing, the oldest grassland fields, especially if they have low productivity: compacted soils due to animal trampling, mixed grassland with too low clover content, or invaded by weeds such *Rumex obtusifolius, Ranunculus* sp., *Poa annua*. On the other hand, maize or wheat mono-culture induces soils problems: soil structure, plant water supply, organic matter decrease, erosion and run-off risks, plant diseases and weed control problems. Thus the usual practice is to alternate grassland and arable crops rather than to use fields for one purpose.

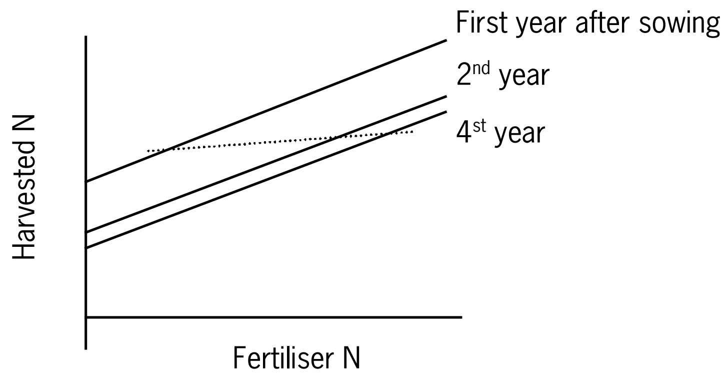


Figure 5. Plant response to nitrogen with time after resowing.

A 'natural decrease' of soil fertility was observed in mountain situations. El Habchi (1993) showed that, at similar N fertiliser supply, the N harvested in grass decreased from the first year after sowing to subsequent years. This decrease in harvested N is not due to a decrease of the apparent productivity of fertiliser N but due to a decrease of the soil N supplying capacity. To maintain yields over the years, it would be necessary to increase the fertiliser input as the age of the grassland increases (Figure 5). As farmers do generally not increase, but on the contrary decrease fertiliser input, this often results in a drop in productivity and in the level of N nutrition of the grassland (Loiseau *et al.*, 1992). In turn, decreased N nutrition also has a negative effect on the persistence of the sown species and on productivity. The drop of soil fertility with time can be related to the continuous accumulation in the soil of root phytomass and in the derived particulate organic matter, with a high N immobilisation capacity.

4.2.2 Methods and periods used for grassland cultivation

The most common tillage method for grassland destruction is deep tillage. If not, farmers use total herbicide destruction (glyphosate), followed by tillage or shallow cultivation, this last practice being encouraged by advisory services (Viaux *et al.*, 1999). No tillage practice is sometimes performed but this has uncertain results.

The frequency of sowing grassland after grassland is now increasing in intensive animal husbandry (Brittany) with the increase of grass in fodder systems (lower production costs per fodder unit). It is carried out in case of soil and/or plant degradation, with or without tillage.

As the most common rotation is grass – maize – wheat, the main period for grassland destruction is late winter – early spring (March). Some farmers (around 10% in the Brittany survey) who want to use the grass for grazing or silage cut during early spring, specially in wet areas, destroy it just before maize sowing in April. In this case the beneficial fertiliser effect of grassland destruction for the maize crop

will be low: nitrogen mineralisation occurs later than maize N demand and uptake capacity; this means that surplus N presents high risks of leaching losses.
In grass-based systems or in soils that are too wet in spring, grasslands are cultivated in late summer/autumn before wheat or a new grassland.

4.2.3 What are the economic costs/benefits of grassland cultivation?

Mono-cultures have a negative impact on soil fertility and on the environment, whereas long rotations that include grass leys increase SOM content, improve soil fertility, reduce weed infestations, decrease erosion and leaching risks, increase yields and limit yield variability (Viaux, 1999). The high mineralisation following grass destruction has a positive effect on the crop production that follows (benefit for farmers), whereas it increases the risks of leaching and gaseous losses (cost for society and environment).

On the other hand, grassland requires no herbicides and less energy inputs. Lambert (1996), applying Life Cycle Analysis methods to evaluate crop performance, showed that the introduction of grass in a maize-wheat rotation decreased the energy need by 22% and the N fertiliser need by 75% (no fertiliser on maize, reduction on wheat).

The cost/benefit of most points is difficult to estimate; this seems to be one of the areas with lacking research. Nevertheless a rough estimation of grassland cultivation costs is indicated in Table 4.

Table 4. Some costs and management practices for grassland renovation.

1.chemical + mechanical destruction (this is the most frequent technique in case of high weed pressure: the main reason for grassland renovation) glyphosate 3.5 l /ha mean: € 26 /ha tillage 2h/ha cultivator roll (to close the soil surface and to limit evapotranspiration) rotational harrow 1h/ha (mean) seeds (in case of grassland renovation) : € 80-85
2. mechanical destruction ploughing the stubbles (February to mid-March) 2 passages (3/4h/ha) tillage + rotational harrow

4.3 Research: state of the art

The effect of grassland cultivation on the bio-geo-chemical cycles consists of the mineralisation of soil organic matter previously accumulated during grassland life. Two kinds of reasons explain why OM accumulates under perennial grassland. The first one is the continuous and plentiful supply of fresh OM from the senescence of the non-harvested plant parts and from animal faeces. The second one results from the conditions prevailing in the soil: 1. the absence of soil perturbation by soil tillage allows protection of this fresh material, which partly accumulates as residues protected in soil aggregates, and 2. in less intensive situations, a low inorganic N availability, partially due to plant N uptake, limits the biological activity of the microbial biomass and reduces the mineralisation rates of the residues.

OM mineralisation in grassland cultivation both depends on the previous management of the grassland, which determines the amounts and quality of the potentially degradable OM and on the techniques used for cultivation and management of the subsequent crops. One can expect that mineralisation after destruction will be influenced by the previous N balance. In France two groups of researchers recently worked on the agronomical and ecological consequences of grassland destruction. In **Auvergne,** most of the studies were devoted to: 1) nature and management of the grassland, 2) the status of soil organic matter at grassland cultivation, and 3) C and N mineralisation after grassland cultivation, as measured *in situ* in a lysimeter with soil maintained bare during three years. In **Brittany**, the studies were aimed at quantifying and modelling N mineralisation kinetics following grass destruction, according to the previous grassland management. These studies allowed to characterise the effect of 1) on 3), and to explain this effect by the more causal effects of 1) on 2) and 2) on 3). Results will be presented by themes.

4.3.1 N mineralisation after destruction

Several experiments were recently conducted in Western France to determine N mineralisation after grassland destruction and to evaluate the risks of N leaching in relation to i) the cumulative nitrogen balance according management practices (fertilisation, grazing or cutting), ii) vegetation type (pure grass or grass/clover swards), and iii) the destruction practices and subsequent soil management. Soil types and date of destruction varied between experiments.

In Brittany, all grassland fields were destroyed in February by glyphosate application. The soils were then kept bare for 2 years. Measurements of water and mineral N in soil (0-80 cm) were performed every 2-3 weeks. These data were used in combination with the LIXIM model (Mary *et al.*, 1999) to quantify N mineralisation dynamics and leaching fluxes *in situ*. Leaching fluxes were validated by comparison with lysimeters and porous cup measurements (Vertès *et al.*, 2001a & b). Simultaneously, soils sampled just after grass destruction were incubated in the laboratory with and without grass residues, for 300 days at 15°C and 90% WFC content. Grass residues were added at the same rate as under field conditions. As an example, Figure 6 shows the comparison between pure grass, only grazed, with moderate fertilisation, on three sites (KL1, KL2 and KZ).

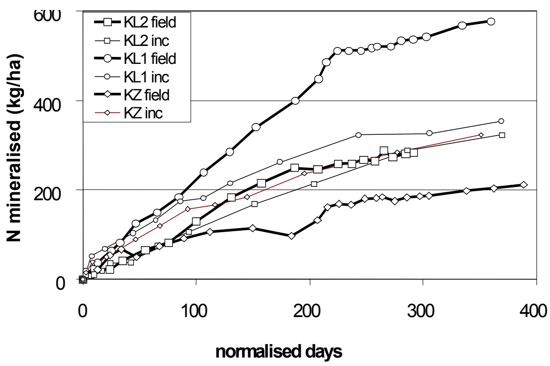


Figure 6. N mineralisation in the field and in incubated soils after pure grass destruction.

The cumulative N balance varied with fertilisation rates and grassland duration (6 years for KL1 and KZ, 4 years for KL2), corresponding to +85, +166 and +158 kg N ha^{-1} yr^{-1}, respectively (Table 5). Stocks of carbon and nitrogen in soils, microbial biomass (at the beginning of the experiments) and plant residues varied slightly between treatments (Table 6). High amounts of carbon and nitrogen were incorporated in soils, especially in the KL2-250 treatment, due to higher C and N contents in the residues.

The LIXIM model was quite well able to reproduce the measurements of mineral N profiles in the bare soil after grassland destruction, suggesting that the simulation of net N mineralisation under field conditions was good. Figure 6 shows the N mineralisation kinetics, either obtained in the field with the LIXIM model or measured in laboratory incubation with grass residues, versus normalised time (i.e. equivalent time at 15°C and water field capacity WFC, Mary *et al.*, 1999).

The main conclusions were (Vertès *et al.*, 2001a & b):
- As expected, high mineralisation rates were observed after grass destruction. N mineralisation was as high as 200 to 450 kg N ha^{-1} during the year following destruction, and 300 to 600 kg N ha^{-1} after 2 years.
- N mineralisation kinetics showed two phases: a fast mineralisation phase from March to November, for about 120 to 200 normalised days, followed by a slow mineralisation phase which may correspond to 'basal' mineralisation coming from humus organic matter.
- The calculated potential mineralisation rate (Vp, slope of each line) varied between 1.1 and 2.3 kg N ha^{-1} day^{-1} in the first phase and between 0.4 and 0.7 kg N ha^{-1} day^{-1} during the second phase.
- Laboratory incubations showed that decomposition of grass residues was nearly complete after 200 days. At this time, the N release due to grass decomposition corresponded to 23-36% of the grass N content. The contribution of grass residues to total soil N mineralisation was low: 16-18% (Table 5).

Table 5. N (or C) mineralisation of grass residues (after 200-260 days incubation) as a percentage of grass-N (or C) or of total mineralised-N (or C).

Period	Site-rate	N mineralised from grass		C mineralised from grass	
		% grass-N	% of total min.	% of grass-C	% of total min.
97-99	KL1-200	36	17.5	30	30
97-99	KZ-250	33	17.6	28	27
99-01	KL2-250	23	15.8	47	34

N mineralisation rates varied between treatments. Several indicators were considered to explain this variability: N balance during grass life; total initial soil organic C and N, soil microbial biomass, C and N in plant residues at grass destruction. None of these indicators could explain the variation in N mineralisation rates (Roué, 2000). Moreover, the N mineralisation rate following grass destruction was weakly linked to the amount of N in grass residues at the time of grass destruction. The net release of N due to grass residue decomposition represented only 16-18% of the total N mineralisation measured in the soil after 200 days of incubation. Therefore, more information on the soil OM compartments seems necessary to account for the C and N mineralisation dynamics after grassland destruction (see 3.2). We hypothesise that the easily mineralisable organic matter may be present in fine particulate organic matter (POM), partly decomposed.

Table 6. *Cumulative N balance, amounts of C and N in soil, in the microbial biomass and in the grass residues at destruction, for pure grass.*

Period	Site-rate	N balance, kg ha^{-1} yr^{-1}	Soil C, t ha^{-1}	Soil N, t ha^{-1}	Biomass-C, kg ha^{-1}	Residue-C, t ha^{-1} yr^{-1}	Residue-N kg ha^{-1} yr^{-1}
97-99	KL1-200	+85	109	11.1	888	3.78	180
97-99	KZ-250	+138	75	6.7	722	3.49	147
99-01	KL2-250	+158	106	10.2	918	5.08	270

The STICS model (Brisson *et al.*, 1998) was used to simulate N mineralisation kinetics in these soils. Parameters of grass residue decomposition and of humified organic matter decomposition were modified in these acidic soils, but the model underestimated N mineralisation. Introducing the hypothesis of a rapidly decomposable POM pool (materials derived from dead leaves, roots or animals with a low C:N ratio) into the model allowed a better simulation of the observed mineralisation kinetics. Work is in progress to test this hypothesis, which was already confirmed by other studies in Auvergne.

Effect of the grassland type and management on C and N mineralisation after cultivation

The role of grassland destruction in the measured mineralisation was calculated assuming that the slow N mineralisation occurring at the end of the soil incubation experiments corresponded to the basal mineralisation of the soils. Figure 7 recapitulates all experimental data in Western France. The Figure clearly shows the high variability in the results, as shown before (120 to 360 kg N ha^{-1} yr^{-1} for similar pastures, without a significant effect of previous fertilisation levels. There is a significant effect of cutting (F) vs grazing (P) after pure grass destruction but this is not significant after grass/clover.

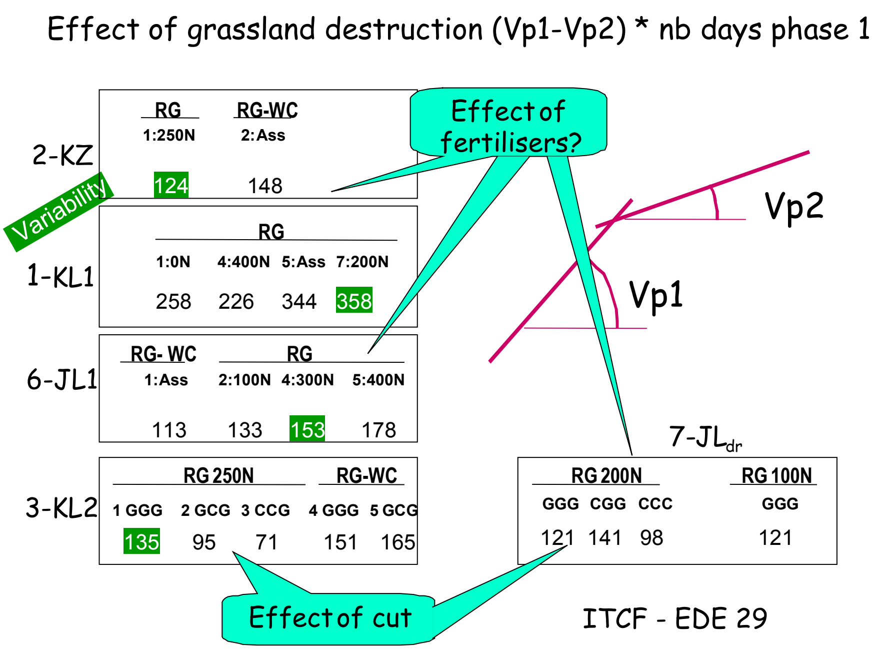


Figure 7. *Estimation of N mineralisation following grassland destruction.*

In Auvergne, mean soil respiration during the three years following grassland cultivation varied from 2.5 to 3.0 t C ha^{-1} y^{-1} (Loiseau *et al.*, 1996). In the first year after cultivation of a temporary ley previously under mowing, N mineralisation varied between 200 and 300 kg N ha^{-1} yr^{-1}. It was not affected by the level of mineral fertiliser during grassland management (300 compared to 0 kg N ha^{-1} yr^{-1}) but there was an effect of the application of slurry (100 compared to 0 kg N ha^{-1} yr^{-1}). A difference between these treatments was maintained during 3 years. In first order kinetics, the mean mineralisable reserve was 3300 kg N ha^{-1} yr^{-1} and its mean residence time was 13 years at the mean temperature of 9°C. The interaction between mineral and organic N fertiliser did not affect the level of the mineralisable reserve but decreased its residence time (Loiseau *et al.*, 1995).

Effects of techniques of grassland renovation

Methods of grassland establishment were studied under the particular conditions of native mountain swards on andosoil with poor DM production (2.5 t DM.ha^{-1}.yr^{-1}) and very high SOM content (260 t C.ha^{-1} in the top 30 cm). The consequences were studied for grass production and SOM fractions. Three methods were compared: 1) conversion of a poor *Nardus* sward to an *Agrostis/Festuca* meadow by simple surface fertilisation without destruction of the sward (Control); 2) direct drilling after chemical destruction of the sward (Direct); 3) resowing after mechanical soil preparation (Rotavator).

After one year, the methods with sward destruction decreased total soil C, especially C in particulate organic matter (POM-C.) The decrease was stronger after rotavation than after direct drilling. After mechanical preparation, part of the POM evolved to the fine SOM particle size fraction below 200 µm but C loss as CO_2 was also higher in this treatment: 11 (Control), 43 (Direct) and 52 t C.ha-1 (Rotavator) (Loiseau *et al.*, 1993). Grass production at the same N fertiliser level was 5.9, 5.3 and 6.1 t DM.ha^{-1}.yr^{-1}, respectively (Loiseau & Bony, 1989). In addition, owing the huge amounts of non-decomposed organic matter, sowing perennial grassland was only possible after a first year of soil preparation including the establishment of an annual crop (Italian ryegrass). In conclusion, satisfactory agronomic performances can be obtained with simple surface fertilisation. Methods of renovation, including the destruction of the initial sward, may increase the costs and the time delay of grassland improvement, and also stimulate the evolution of SOM, resulting in important emissions of greenhouse gases.

4.3.2 Soil quality

OM status under permanent grassland or grass-arable leys

A long-term experiment in Brittany, comparing the plant and soil characteristics of several fodder rotations (Simon, 1992, Vertès *et al.*, 2001c), showed the positive effect of grassland duration on SOM content in a loamy sandy soil (Figure 8). The plots with maize and *Lolium multiflorum* (6 months) had the highest production (15 t DM ha^{-1} yr^{-1}) but showed a strong decrease in organic C and N in the soil. The plots with only maize and those with maize and *Lolium multiflorum* (18 months) had a similar productivity (13 t) but the grass limited C and N decrease in soils. Pure cut grass (*Lolium perenne*) had a lower productivity (11 t) but also the highest total soil C and final N status, together with higher microbial biomass content, earthworm population and diversity (Binet, 1993).

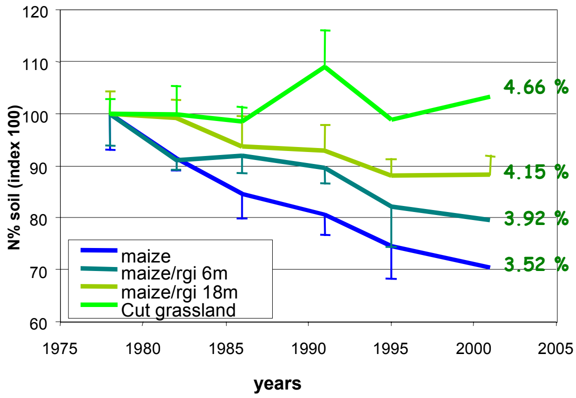


Figure 8. Course of total N in soils in three rotations, including grassland vs maize + bare soil ; rgi is italian ryegrass (Lolium multiflorum Lam.)

In Auvergne, a rotation of temporary grass ley with cereals on a sandy soil at 800 m altitude showed, under intensive fertiliser management for hay or silage, a negative N balance during the crop years. Also the N budget of the newly sown grassland was negative during the first year after sowing. The N balance of the grassland became positive from the second year and increased from year to year. In the absence of N leaching, this denoted soil N accumulation (Loiseau *et al.*, 1992). In this long-term experiment (20 years), both mineral and organic N fertiliser increased SOM accumulation. Therefore, N availability determined the level of SOM accumulation under grassland as a result of increased production: C accumulation in the top 20 cm of the soil increased from 38 to 53 t C ha^{-1} as the DM harvests increased from 5 to 11 t DM ha^{-1} yr^{-1}. But no further soil C accumulation occurred for harvests from 11 to 14 t DM ha^{-1} yr^{-1}: at a very high N supply, either the OM input to the soil could be reduced as a result of an increased harvest index, or soil OM accumulation could be decreased at similar OM input to the soil, due to a decrease of the yield of the OM input in soil OM. It is hypothesised that the lower C:N ratio of the SOM input and changes in microbial activity could be involved in such a negative response of SOM to high N fertiliser rates.

SOM compartments

Specific soil OM compartments increase in grassland soils, whereas some others remain stable. Therefore, some studies focused especially on the measurement of the SOM compartments, in order to detect which were affected most. Two main SOM compartments increase in the soil as a result of fresh OM input from non-harvested grassland material: 1) particulate OM above 200 µm (POM) results from the accumulation of root residues, non- metabolised by microbial biomass; 2) the organo-mineral fraction below 50 µm (AOM) represents a more stable fraction of SOM; 3) extractable OM (EOM), results mainly from the turnover and activity of the microbial biomass, using part of the residues and of the POM as substrates (Alvarez *et al.*, 1998; Assman *et al.*, 2001).

Mineral fertiliser (300 kg N ha^{-1} yr^{-1}) increases C accumulation in AOM, whereas organic fertiliser (100 kg N ha^{-1} yr^{-1}) increase both AOM and POM (Loiseau *et al.*, 1996). In grazed grassland, not receiving any fertiliser N, the presence of white clover increased EOM and decreased POM (Assman *et al.*, 2001).

Finally, N availability seems to regulate the pathways according which the OM input evolves in the soil in temporary grasslands: 1) the residues tend to accumulate in POM in situations with low or moderate amounts of inorganic N and with a high C:N ratio of the OM input to the soil; 2) microbial metabolites accumulate in EOM under low growth limitation by N and a balanced C:N ratio of the organic input (mixed swards); 3) stable organic matter is subjected to a fast turnover in highly fertilised grass swards, where carbon availability is the limiting factor of the microbial activity. Both the quality of the plant residues (C:N, lignin N) and the inorganic N availability seem to control the nature of soil activity and SOM transformations (evolution rate, transformation vs metabolisation of the OM input, growth efficiency and turnover of the microbial biomass).

Relation between SOM compartments and C and N mineralisation

In mown grassland, as well in grazed pasture with and without white clover, soil C and N mineralisation appears to be closely related to the amounts of the different SOM fraction accumulated under the grassland at cultivation. Soil respiration in different cropping systems depends on total soil C. Nevertheless, the relationship is different, depending on the cropping system. For all cropping systems, a closer and more general relationship exists between soil respiration and the amounts of C present in the coarser SOM fractions above 50 µm (Loiseau *et al.*, 1993). After cultivation of a temporary ley, the mean yearly loss of C during 3 years increased from 2.5 C ha^{-1} yr^{-1} (control grassland, non-fertilised) to 2.9 with slurry (100 kg N ha^{-1} y^{-1}) and to 2.8 with mineral N (300 kg N ha^{-1} yr^{-1}) previously applied to the grass crop.
Three main SOM compartments account for the dynamics of N mineralisation after grassland destruction. The basal, long-term, N mineralisation is related to the loamy particle size fraction with a long residence time (AOM). The major part of the soil N that can be mineralised in the first few years after cultivation is related to the extractable SOM fraction with a medium residence time (EOM) . The short-term mineralisation after grassland destruction is also due to plant residues of which net N mineralisation depends both on the amount and on the C:N ratio of POM (Assman *et al.*, 2001).

4.3.3 Crop/animal performance (yields, quality, pest/diseases, etc.)

Network and experimental results

Fifty 4- to 10-year-old grassland fields in Brittany (mainly East Brittany) have been destroyed in late winter or spring (1996 to 1999) before cultivation with maize for silage. Net nitrogen mineralisation on all these fields was calculated as follows:

N mineralised = N end - N initial + N leached + N uptake.

Gaseous losses were considered as negligible (well drained soils, lack of experimental data)

For 80% of the fields, net mineralisation calculations yielded values between 200 and 350 kg N.ha^{-1}.yr^{-1}. The fields below these values corresponded to late destruction of the grass (May/June). Above 350 kg N.ha^{-1} they were often ‘parking areas’, near the milking place, with very high stocking rates. The maize (silage) production levels observed after grassland destruction were quite good: 15 to 18 t ha^{-1}, 10-15% more than control maize in the same year.

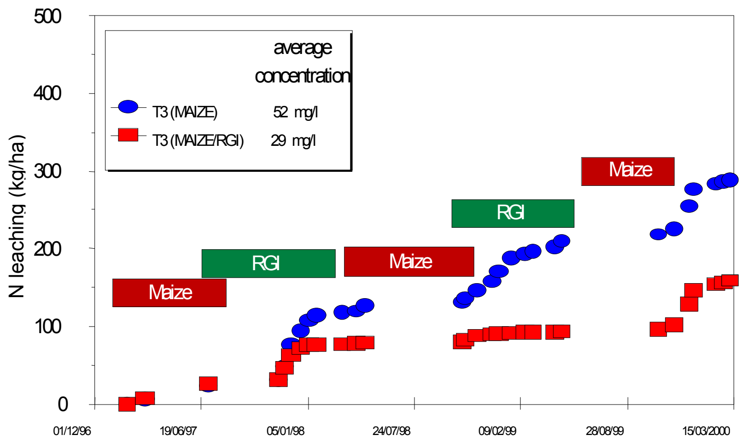


Figure 9. *Effect of Italian ryegrass sown under maize on leaching losses, vs maize + bare soil (ITCF-EDE29).*

In the trials presented in section 3.1, most of treatments were uncropped, but some were cultivated; here, mean maize production was 17.3 t DM ha^{-1} yr^{-1}. The production of under-sown Italian ryegrass was measured at maize harvest, then just before grass destruction at the end of February. Results varied with climatic conditions and N availability. For the low and high mineralisation treatments (MP2 and MP1 in Figure 9) the respective yields were 0.1 and 0.25 t DM ha^{-1} in autumn and 2.5 and 4.7 t DM ha^{-1} at destruction, representing an N uptake of 62 and 106 kg N ha^{-1}. The use of surplus nitrogen by under-sown rye grass strongly limited N leaching risks compared to maize with bare soil, as shown in Figure 9. A different trial showed the positive effect of a rape–wheat rotation after grass destruction in late summer, compared to a wheat–rape succession.

Modelling effect of leys-arable rotations

The environmental risks of three crop rotations were compared under several soil-climate conditions (Morvan *et al.*, 2002):

Rot 1: grass/clover grassland (5 years) – fodder beet – winter wheat: typical for low input systems

Rot 2: grass/clover grassland (5 years) – maize – winter wheat: typical for semi-conventional systems with lower herbage part than mixed systems

Rot 3: grass/clover grassland (5 years) – winter wheat – winter wheat: very frequently occurring in 'full grass systems', or in mixed systems when the proportion of cereals to be sold is important.

Both plant and soil data have been simulated by the STICS model (Brisson *et al.*, 1998), activated from grassland destruction until the end of the subsequent second winter. Experimental data (successive soil mineral N profiles, crop measurements) were used to calculate the value of model parameters in two soils for three climatic scenarios (including soil and climate of 1996-1998 of the experimental field). Nitrogen mineralised from the green parts of fodder beet, left on the soil after the crop, was taken into account. The main results were :

- Low amounts of mineral nitrogen in soils before grassland destruction in late winter (also observed in the network survey).
- As following spring crop, fodder beet was able to take up more than 300 kg N ha^{-1} yr^{-1} in four of the six simulations, while maize uptake was never more than 175 kg ha^{-1}. Some 'luxury uptake' of soil nitrogen may be achieved by fodder beet, of which the nitrogen content in leaves may vary from 2.2 to 3.4% at the same DM production.

- Thus mineral nitrogen in autumn after harvest was lower in beet plots (20 to 60 kg ha^{-1}) than in maize plots (200 to 280 kg ha^{-1}). As winter wheat is unable to use this nitrogen, high leaching losses may be expected during the first winter after grassland destruction.
- Green parts of fodder beet, left on the soil after harvest, contain an average of 130 kg N ha^{-1}. As they have a low C/N ratio, quick mineralisation is to be expected (Nicolardot *et al.*, 2000, Trinsoutrot *et al.*, 2001). Morvan *et al.* (2002) measured a mineralisation of fresh beet residues during the following winter that was equivalent to 25-40 kg N ha^{-1}. Thus, the additional risk of leaching losses associated with this crop is low.

Figure 10 shows the cumulative leaching losses for the two years following grass destruction. Mean cumulative leaching is estimated at 110, 270 and 240 kg N-NO_3 ha^{-1} respectively for rotation 1, 2 and 3. The lower variability that was observed for rotation 1 indicates a good ability of fodder beet to reduce the environmental risk, compared to maize, mainly under risky conditions such as shallow soils. Part of the variability is explained by drainage (soil depth and rainfall conditions). Fodder beet were able to an N uptake up to 400 kg ha^{-1} (measured in September) and had already absorbed 125 kg N ha^{-1} in June; this was all the available mineral N in the soil over this period. This confirms that fodder beet can trap large amounts of nitrogen after grassland destruction.

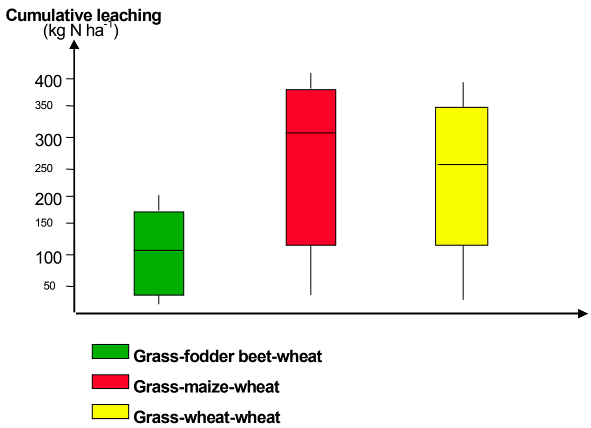


Figure 10. Comparison of modelled cumulative leaching in three typical rotations, after grassland destruction.

4.3.4 Farm management en economics

The current advisors message is: no N fertilisation is necessary for the crop following early spring grassland destruction. If maize is cultivated during 2 years, it is necessary to under-sow some catch crop such as Italian ryegrass to reduce leaching risks. Wheat after maize does not reduce leaching losses very much. As grassland destruction implies high amounts of nitrogen mineralised and difficulties to trap it, some thought must be developed to optimise fodder systems in view of the part of the grassland area that is destroyed every year. Laurent *et al.* (unpublished) propose some quantification of the amounts of N mineralised after destruction (kg ha^{-1} yr^{-1}). Available N for maize (or spring crop) varies between 50 to 300 kg N ha^{-1} yr^{-1} during the year following destruction, 0 to 115 kg N ha^{-1} yr^{-1} in the second year, 0 to 30 kg N ha^{-1} yr^{-1} in the third year and insignificant effect thereafter, depending on grassland age at destruction (1-2 years, 3 to 5 years, 6 to 10 years, more than 10 years). A coefficient 'management' could be applied for the calculations: only grazed = 1; only cut = 0.4; grazed and cut = 0.7.

Conclusions and prospects

New hypotheses and projects result from the present knowledge. Further studies will concern the biogeochemical CNP cycles, during grassland management and at cultivation. New research will include functional approaches in grassland microcosms as well as the setting up of new long-term field experiments (ORE) at Lusignan and Clermont-Ferrand-Theix, both included in a national INRA network.

1) Functional aspects
Field and incubation studies in Brittany showed that the mineralisation of fresh plant residues alone could not account for the initial high N mineralisation rates observed in the field after destruction of grassland. Some progress was obtained concerning the effect of grassland type and management on SOM accumulation in several SOM compartments: plant residues, but also microbial metabolites and the more stable humus fraction. The dynamics of the N supplying capacity of bare soil was also related to these SOM compartments, of which the turnover times were characterised after grassland destruction.

Research needs concern the evolution of SOM compartments, especially the fate of the fresh organic input from grassland, in order to explain why they can accumulate under grassland and mineralise after destruction (Mary *et al.*, 1996). Major attention will be paid to root litter. Both the nature of the dead plant material incubated in the soil (species, chemical composition) and the conditions prevailing in the soil (N availability; presence, nature and activity of the living plant; type of soil perturbation) may drive the transformation and the mineralisation of root residues. New experiments will be founded on the concept of plant trophic strategies and will be conducted with grassland monoliths, using stable isotopes of C and N (Thesis of E. Personneni, Clermont-Ferrand, in collaboration with INRA Agronomy Laon and Soil microbiology CNRS Lyon).

It is also hypothesised that the strong N flux after grassland destruction could be the result of the short-term change in C and N fluxes in soil induced by grass canopy destruction, and of rapid consumption of a labile nitrogen pool by the soil microflora (rhizodeposition and/or microbial nitrogen). To investigate the key processes responsible of the increased net N mineralisation, the use of isotopic techniques (^{15}N and possibly ^{13}C) are crucial for an independent quantification of gross N mineralisation and immobilisation and to relate these to changes in C dynamics. Future research aims at quantifying gross mineralisation and immobilisation fluxes under bare soil after grassland destruction and in actual pure grass sward. Experimentation will consist of a dynamic assessment of these fluxes so as to study the relative changes in mineralisation and immobilisation over the season before and after destruction of grass, and to compare this evolution with net N mineralisation measurements.

At some steps, it is contemplated to measure C rhizodeposition parallel to N fluxes in order to link C and N dynamics. This project will combine work under field conditions and under controlled conditions. Part of the methodological and mathematical tools are available (^{15}N injection, FLUAZ model, growth labelling chamber with controlled ^{13}C atmosphere). Nevertheless this work will imply i) to modify the existing version of the FLUAZ model to take into account the process of N uptake by plants, ii) to adapt/develop a method concerning labelling techniques in grassland (levels of addition, experimental design, duration, etc.) , iii) to develop techniques using ^{13}C and ^{15}N labelling simultaneously.

2) Long-term field experiments
Determination of C storage ability in grassland is of great interest now. It is thus necessary to characterise the effect of factors such as grassland type (composition, permanent or temporary), fertilisation intensity and use intensity. In case of temporary grassland, the rotation will be studied to determine the direct and late effects of each crop type.

- Rotation of temporary grassland will be studied at INRA Lusignan in collaboration between agronomy and animal husbandry (INRA Rennes - Quimper): they will focus on grassland persistence and on the biochemical cycles in rotations with different nature, life duration and intensification of the temporary grassland.
- Permanent grassland will be studied at Clermont-Ferrand-Theix in collaboration with INRA animal husbandry and agronomy Toulouse): they will focus on the de-intensification of permanent grassland, crossing two factors: decreased stocking rate and decreased level of N nutrition.

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5. Future challenges in grassland cultivation in Germany

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Abstract

Grassland in Germany covers a wide range of management intensities and as a consequence also a wide range of plant communities. Whereas extensively managed grassland is very often well balanced in botanical composition, intensively managed swards often deteriorate and have to be resown in order to maintain a well performing sward in terms of productivity and quality of herbage. Latest developments indicate that permanent grassland is increasingly transformed to ley farming systems and forage crop rotations including forage maize. Results from an interdisciplinary research project are presented highlighting the nitrogen fluxes in different forage production systems.

Introduction

'Grassland cultivation' as the common expression for grassland renewal (grass is resown after ploughing) and for short term grassland in rotation with arable crops (ley farming) is challenged by increasing demands with respect to sustainability of land use systems and quality of forage for high merit dairy cows. Recent developments in Germany indicate that permanent grassland becomes less favourable from an agronomic point of view due to higher costs of production and a lower energy content of herbage compared to arable crops like silage maize. With respect to ecological aspects, however, appreciation of permanent grassland has been recently elevated by legislation in Germany due to the positive performance of grassland in terms of biotic diversity, erosion protection and carbon sink. It is the unique responsibility of grassland scientists to develop land use systems meeting the economic demands of the dairy industry as well as the ecological demands imposed by society.

5.1 General information

5.1.1 Key figures on the intensity of grassland use in Germany

Grassland in Germany has to be divided into at least two categories. Areas that are used as grassland exclusively due to climatic (short vegetation period), soil (e.g. peaty soils) or water (e.g. high groundwater level, high precipitation) constraints are described as 'obligatory grassland', those that could also be used for arable crops are described as 'facultative grassland'. As a consequence, the first category is not relevant for discussions about alternative crops for milk or meat production or forage crop rotations. In general it can be summarised that grassland in the mountain regions of southern Germany can be characterised as obligatory grassland due to altitude, precipitation or inclination. These climatic and pedological conditions are significantly different from the low-land areas in the north of Germany. Due to these differences in environmental conditions different 'philosophies' of grassland management have been developed in the northern and the southern states of Germany. While multi-species swards are still highlighted in the mountain regions, rather simple swards based on a high percentage of perennial ryegrass are preferred in the north.

From the botanical point of view it can be concluded that grassland in the south of Germany is corresponding with similar locations in the alpine countries (e.g. Austria or Switzerland) whereas the swards in the northern regions are much more similar to those that are typical in the Netherlands or in Denmark. To simplify the description of the situation in Germany we will focus in the following chapters mainly on the situation in northern Germany.

Figure 1 gives an overview of the distribution of grassland in Germany expressed as percentage permanent grassland of the total agricultural area. There are three main grassland-dominated regions exceeding 50% of the agricultural area. Beginning in the south, these are the foothills of the Alps and the Alps themselves, the highlands in central Germany and the coastal regions in the north. Figure 2, which shows the livestock units per ha, expressed in dairy cows per 100 ha, is well correlated with the pattern of distribution of grassland in Figure 1. However, these data emphasise that overall averaged data for Germany do not give a realistic picture as the various regions differ strongly in the extent of specialisation on milk or beef production.

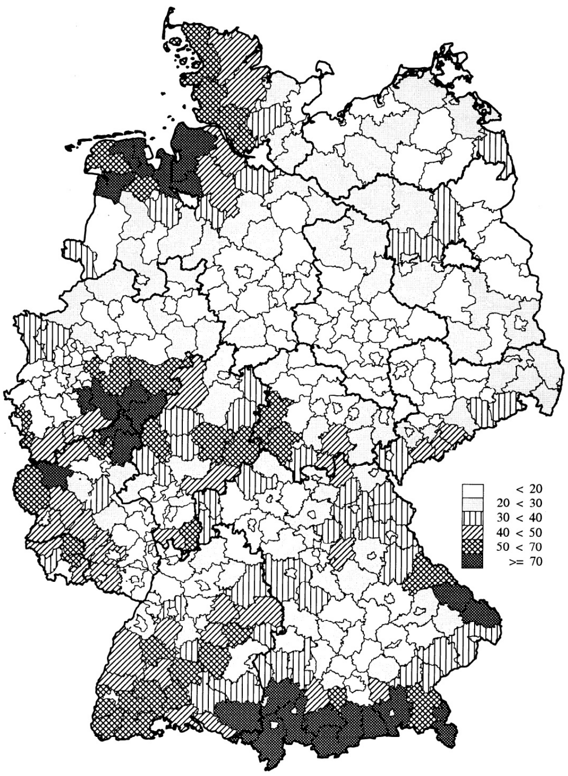

Figure 1. *Proportion of permanent grassland in Germany in 1996 (100% = total agricultural area) (Doll, 1996).*

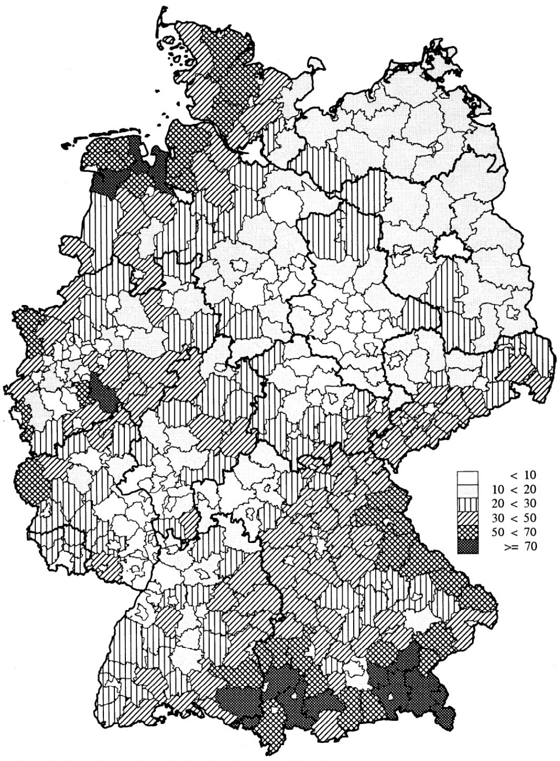

Figure 2. *Number of cows per 100 hectare in Germany in 1996 (Doll, 1996).*

Another topic, namely the structure of the dairy farms has to be taken into account to characterise the differences in grassland/forage management systems in Germany. Figure 3 shows the distribution of big dairy farms with more than 40 cows per farm in the western states of Germany and more than 100 cows per farm in the East. These figures are relevant for the discussion of perspectives for grassland cultivation in the future, as it indicates the limitations of grazing systems due to increasing herd sizes in the various regions. From these figures it becomes evident that the eastern and northern states are again very different from the situation in the south.

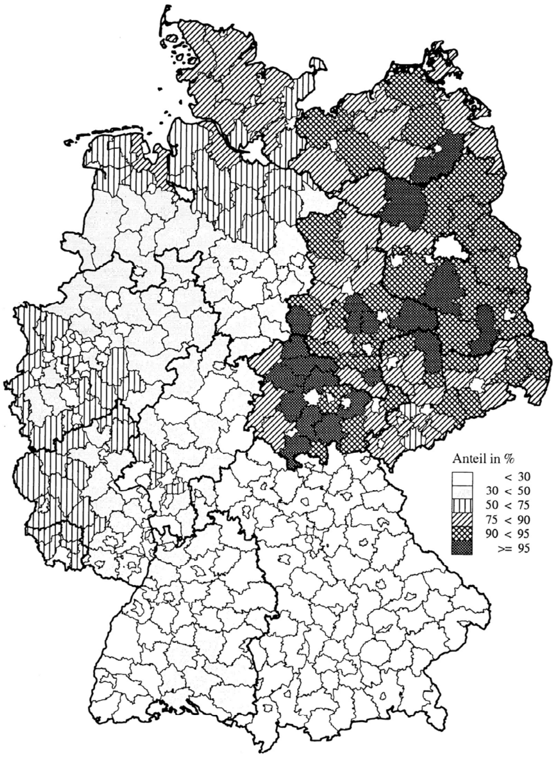

Figure 3. *Proportion of cows in 'big herds' in Germany in 1996 (>100 in eastern Germany; >40 in western Germany) (Doll, 1996).*

Focussing on the situation in the north a reliable dataset is available indicating the actual intensity of grassland management in 'typical dairy farm enterprises' in the state of Schleswig-Holstein in the very north of Germany. The so-called 'Dairy Report' (Deerberg, 1998), published annually by the Agricultural Chamber of Schleswig-Holstein, is based on data from more than 1600 dairy farm enterprises. These are the most reliable management data of commercial farms in Germany. Table 1 gives an overview on the management intensities in terms of nitrogen budgets on grassland as well as on the most important arable fodder crop, which is silage maize. The corresponding livestock unit per hectare is 1.7. Some of the data for pastures are added from recent field experiments (Ingwersen, 2001).

Plotted against time it can be concluded that the N surplus reached maximum values in the beginning of the eighties and decreased since that time. During the last 5 years N surpluses for the above-mentioned fodder crops were rather constant.

5.1.2 Key figures on the intensity of grassland cultivation

The main problem to give reliable figures on the quantity of grassland cultivation is the lack of statistical data dealing with grassland renewal covering the total area of Germany. The only available data are figures on the amount of grass seed sold. This gives an idea of the amount of grassland renewal, but it does not allow to distinguish between the different methods of grassland cultivation, like oversowing, resowing or growing grass as an arable crop in a crop rotation. In total, grassland seed sold in Germany within one year would be sufficient to reseed approximately 8-10% of the total grassland area.

Table 1. N balances of a number of forage crops in Schleswig-Holstein. Data from Deerberg (1998) and Ingwersen (2001).

	Maize (silage)	Cut grass (silage)	Pasture
Input (kg N ha^{-1})			
Mineral N fertiliser	48	210	160
Slurry	128	88	30
Excrements	-	-	60
(Leguminous N)		(30)	(30)
(Deposition)	(20)	(20)	(20)
Total input	176	298	250
Output (kg N ha^{-1})			
Crop yield	106	200	-
Animal products	-	-	32
Total output	106	200	32
N surplus (kg N ha^{-1})	+70 (90)	+98 (148)	+218 (268)

Underlying data: 4 kg N m^{-3} slurry, 200 grazing days x 0,3 kg excrement N (pasture); Maize: 9.5 t DM ha^{-1}, 7% CP; Grass silage: 7.8 t DM ha^{-1}, 16% CP; Pasture: Gross DM yield minus crop residues x 0.25 (N use efficiency of milk production)

Wachendorf & Taube (2001) analysed more than 200 permanent grassland swards in northern Germany with respect to plant species diversity and features of productivity (Table 2). They found that less than 10% of these swards were less than 5 years old, whereas more than 50% had not been resown within the last 30 years. Only about 10% of these swards had been oversown during the last years. There was also a significant difference between conventionally and organically managed swards, indicating a higher proportion of ley farming systems on organic dairy farms. If grassland renovation is necessary, most farmers prefer to do so by ploughing. Reseeding without ploughing is not popular on mineral soils, whereas it is on organic soils.

Obviously, grassland cultivation is mainly used to switch from a permanent grassland system to a ley farming system. This is confirmed by statistical data on the proportion of permanent grassland plotted against time. For example, the proportion of permanent grassland has decreased in Schleswig-Holstein within the last ten years from 46 to 42 % of the total agricultural area.

5.1.3 Legislation with respect to grassland cultivation

The Federal Nature Protection Amendment, which became a legal instrument in 2001, prevents grassland renewal by ploughing in environmentally sensitive areas. In addition to that, voluntary contracts between farmers and water supply and distribution companies may limit grassland renovation activities.

Table 2. Classification of swards according to fertilisation intensity and sward age as well as number of swards with oversowing (northern Germany) (Wachendorf & Taube, 2001).

	Organic [n]	**Conventional** [n]
Fertiliser Intensity		
0 kg N ha^{-1} yr^{-1}	38	0
0 – 50 kg N ha^{-1} yr^{-1}	52	6
50 – 100 kg N ha^{-1} yr^{-1}	12	20
100 – 220 kg N ha^{-1} yr^{-1}	0	46
> 220 kg N ha^{-1} yr^{-1}	0	35
Sward age/Oversowing		
2 to 6 years	20/-	10/2
6 to 10 years	19/1	15/3
11 to 15 years	13/1	12/2
16 to 20 years	20/2	6/-
21 to 30 years	6/-	12/5
31 to ... years	24/-	52/-
Total number of swards	102	107

5.2 Farmer's situation

5.2.1 What causes the need for grassland cultivation?

There are no reliable data characterising the motivations of farmers to reseed grassland. Two major reasons, however, are evident. One reason for the need of grassland renovation is the botanical degradation of swards. While *Elymus repens* L. is the most important unsown grass ('weed'), responsible for sward degradation in the regions of intensive grassland management in the north*, Rumex obtusifolius* L. plays this role in the south. The other reason, which is relevant especially on clay and loamy soils, is the complex of soil compaction caused by intensive wheel traffic with harvesting machinery as well as with slurry application machinery imposing a lack of oxygen in the upper soil layers and as a consequence a decline in the performance of the sward. But, as mentioned above, the quantitative relevance of these specific reasons can hardly be estimated.

5.2.2 Farmer's criteria for decisions of grassland cultivation

The extend of grassland cultivation is depending on the expected economic benefit of the procedure. On intensively managed dairy farms with a high milk yield per cow the need of high energy contents in forages is the main reason for frequent grassland cultivation. Under these circumstances there is actually a tendency coming up to transform permanent grassland to short term ley systems including maize in a crop rotation. Table 3 gives an overview of the energy value of various forage crops in northern Germany. The actual situation on commercial farms is represented by data from Deerberg (1998), data from our research station characterise the potential energy value (without any losses).

Table 3. Net energy content of various forage crops in northern Germany.

Data source	Cut grass (silage) 1st/2nd cut	Pasture	Maize (silage)	Cereal whole crop silage
		(MJ NEL kg DM^{-1})		
Deerberg (1999) (average 1995-1999)	5.8	- not available -	6.4	6.0
Ingwersen (2001) & Herrmann *et al.* (2001) (average 1997-1999)	6.5	6.8	6.8	6.6

NEL = Net Energy for Lactation

It is evident, that in intensive production systems permanent grassland, used by cutting, cannot compete with maize or high yielding cereals grown for whole crop silage. In extensive grassland systems, however, which play a dominant role in the rural areas of the highlands and also in the peatlands of the river valleys in the north, which are more suitable for suckler beef production than for milk production other constraints than energy value are dominating farmers criteria for decisions on grassland cultivation. The main criteria in the choice of type of grassland cultivation is the goal of reducing production costs. Cleaning cuts and – to a certain extend – oversowing are very often the spare grassland cultivation procedures in extensive grazing systems. Table 4 gives an overview of the costs of different measures of grassland cultivation.

Table 4. Costs (€ ha^{-1}) of different methods of grassland renovation.

Cost category	Oversowing with common farm equipment	Oversowing with special machinery	Direct drilling with non-selective herbicide	Reseeding with plough	Reseeding with non-selective herbicide and plough
Machinery	35	50	110	160	175
Selective herbicide	0	0	23	23	23
Non-selective herbicide	0	0	48		48
Seed	30	30	45	45	45
Total	65	80	226	228	291

5.3 Research: state of the art

5.3.1 N cycling

Data of an integrated research project are used to illustrate the problems the actual forage production systems are facing in view of increasing demands by environmental policies. Firstly, the N status and leaching losses of various grassland systems are shown, together with the respective figures for silage maize. Then the results will be discussed and conclusions for improved production methods will be drawn.

The integrated research project was established in 1997 by several Institutes of the University of Kiel. The experiments took place on the experimental farm 'Karkendamm' (∅-precipitation 802 mm; ∅-temperature 8.3 °C; soil type: podsol; pH 5.6). At farm level, measurements of the main N flows were done for different levels of intensities and strategies of management, aiming to improve the efficiency of the transfer from input N to product N in milk and meat (Taube & Wachendorf, 2001; Wachendorf & Taube, 1999). The following topics were focused on: I. Impact of soil nutrient supply on N efficiency of various fodder plants. II. Contents of legumes (white and red clover) in permanent grassland and forage leys, respectively, as critical parameters of performance of both swards and animals. III. Impact of a simultaneous supply with high energy and N rich substances on biosynthesis in rumen. IV. Supplementary diets for grazing cows depending on fodder quality and –intake. V. Economic analysis of single means as well as of combinations of means. The grassland plots, comprising 2 ha, were established on a 4 year old grassland oversown with seeds of clover/grass in the year before the start of the project. Grazing was carried out with heifers due to the limited area of paddocks (1500 m² each). The experiment included the factors i) management system (cutting vs. grazing), ii) cattle slurry (0 vs. 20 m^3 ha^{-1} yr^{-1}) and iii) nitrogen fertiliser application (0 to 300 kg N ha^{-1} yr^{-1}). At each defoliation amounts of biomass, protein-, fibre- and energy content were measured and the clover content of the swards was recorded. ^{15}N-labelled mineral N fertiliser and slurry were used in all trials to assess the portions of N taken up by the plants from the various N sources in the root zone. Moreover, the amount of N fixed by the clover was determined by ^{15}N techniques. For leaching measurements a total of 1300 ceramic cups were installed below the grassland and maize plots connected to a central pumping station by about 15 000 meters of plastic pipes laid 50 cm below surface. Leachate samples were taken at weekly intervals throughout the leaching period. The pump was controlled by tensiometers installed in several soil layers activating the pump only when a critical soil water tension was reached.

The maize experiment was established in 1997 with three cattle slurry application rates (0, 20, 40 m^3 ha^{-1}) and 4 nitrogen fertiliser treatments (0, 50, 100, 150 kg N ha^{-1}) (Jovanovic *et al.*, 2000). Understorey treatments included ryegrass, drilled between maize rows. Prior to the trial, maize had been grown in monoculture for many years. Maize (cv. *NAXOS*, early maturing class) was planted at the beginning of May. Immediately after ploughing, the cattle slurry (1.8 kg N m^{-3}, 0.5 kg P_2O_5 m^{-3}, 2.0 kg K_2O m^{-3}) was strip-spread and incorporated into the soil. All plots received a fertiliser dressing of 30 kg P ha^{-1} by side dressing and a broadcast application of 35 kg P ha^{-1}. Nitrogen fertiliser (calcium ammonium nitrate) was applied in equal dressings at the one-leaf and eight-leaf stage of maize. Ryegrass was sown at the 2 to 3 leaf stage of the maize between the maize rows at a rate of 6 kg ha^{-1}.

Balances provide interesting insight into the N budget of grassland systems. The output of N by cutting for silage and/or by retention in grazing animals increases with increasing N supply. At a given N supply the output is highest for swards that are only cut but it is reduced with increasing grazing intensity of swards. The latter is due to the low N retention of growing animals, which is somewhat lower than 10% of the N offtake. Thus surpluses of N calculated from balances of the investigated grassland systems are highest for grazed and lowest for cut swards with hay pasture systems (one or two cuts and succeeding grazing) intermediate (Figure 4). These results highlight the increased risk of N losses to the environment by nitrate leaching or gaseous emission.

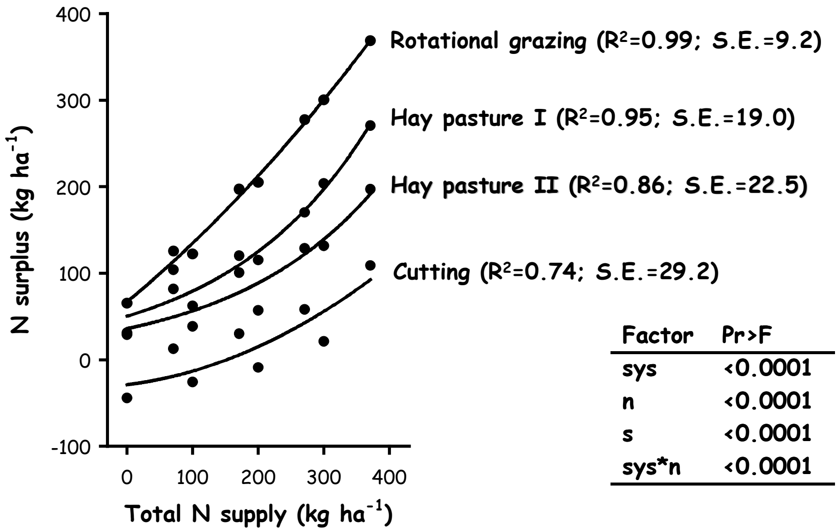

Figure 4. *N surplus on grassland under various management treatments (total N supply is N from mineral fertiliser plus slurry (n), sys=management system) (Trott, unpublished).*

The cumulative climatic water balance at the experimental site amounted to 342 mm on average for the experimental period 1997-1999 with 40% of the total yearly precipitation occurring over winter. Longer frost periods did not occur. Leaching losses were strongly affected by the management system with lowest N losses in the cutting system and highest values under grazing and with both hay pasture systems intermediate (Figure 5). In each system N losses increased with increased N input.

Generally, the slope of the regression lines increased with increasing grazing intensity, possibly reflecting compensatory effects of fertiliser and symbiotic N at low levels of total N supply. It is noteworthy that most values are well above the EU drinking water limit of 38.6 kg N ha^{-1}, which corresponds to 50 mg NO_3 l^{-1} with an average amount of leaching water of 342 mm. Though leaching losses for grazed clover-based systems are lower than for intensively fertilised systems, they are still above the EU limit for drinking water.

The results highlight the increased risk of nitrate contamination of groundwater under grassland intensively grazed by cattle. Reducing the N return by grazing animals by incorporation of one or two cuts provides a promising tool towards an environmentally sound grassland management.

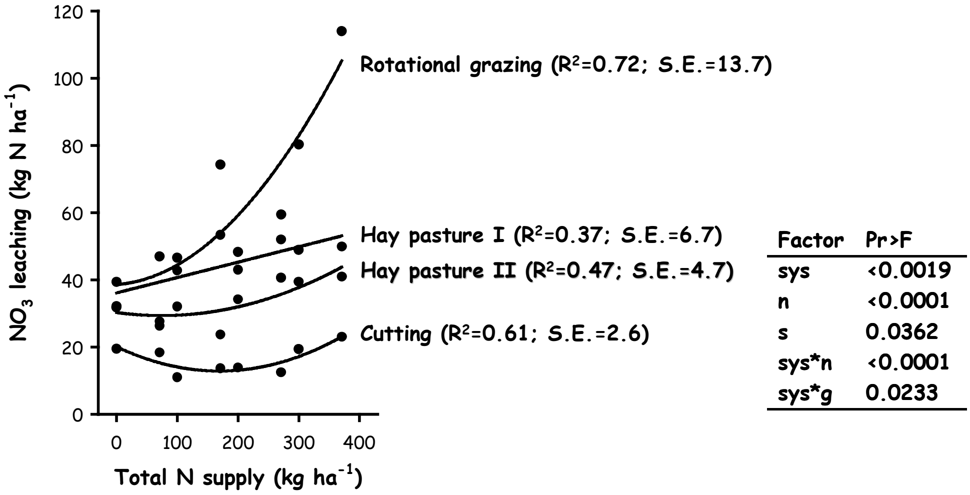

Figure 5. *Nitrate leaching losses (kg N ha⁻¹) on grassland under various management treatments (total N supply is N from mineral fertiliser plus slurry (n), sys=management system) (Büchter et al., unpublished).*

The amount and distribution of rainfall is a crucial factor determining leaching of nitrate. Mean precipitation was 824 mm for the two experimental years. Considering the field capacity of the soil of 94 mm and an estimated amount of evaporation, 350 mm leachate percolated through the soil. Given this amount of leachate, the actual EU limit for drinking water (50 mg NO_3 l^{-1}) yields an amount of 40 kg N ha^{-1} that may leach during winter. The figures for maize indicate that an increased supply of N by slurry and mineral fertiliser increases leaching of nitrate (Figure 6, Table 5). Growing *Lolium perenne* L. as an understorey significantly reduces leaching losses. The nitrate concentrations of the leachate in the understorey treatment were generally well below the EU limit for drinking water. These results show that silage maize grown in monoculture causes less groundwater pollution by nitrate than grassland. Thus an appropriately managed maize crop can contribute positively to the protection of water in regions with very sandy soils.

From these results it can be concluded that high N surpluses and leaching losses are possible on grassland, unless it is used by cutting, where the bulk of the available N is removed with the crop. Silage maize, on the other hand, shows a high N use efficiency when N is applied in moderate amounts and causes only minor N losses to the groundwater.

In view of increasing demands of environmental policies dairy farms will have to tackle the problem of high N surpluses in the future. While effects of increased N retention in animals are limited due to physiological reasons there is scope to meet the goal by optimising the N use efficiency of forage production. One way may be the reduction of grazing and fertilising intensity on grassland. Another strategy is to include grassland as a short-term ley in crop rotations. In this way, possible surpluses from the ley phase could be used efficiently by the following maize crop. On the other hand, negative ecological effects of maize cultivated in monoculture, like soil erosion or humus degradation, might also be reduced by cultivating maize in a crop rotation. To evaluate the potential of this strategy, a field experiment was established in 1998 at the same site as the permanent grassland and maize trials. The goal is to provide data on productivity and herbage quality for a crop rotation over a wide range of fertiliser intensities. The underlying data for adjusting stocking densities and amounts of slurry are deduced from a typical specialised dairy farm in northern Germany with an average stocking density of 1.7 LU ha^{-1}, 100 grazing days for cows and young stock. In such a scenario about 25 m^3 slurry ha^{-1} would be available.

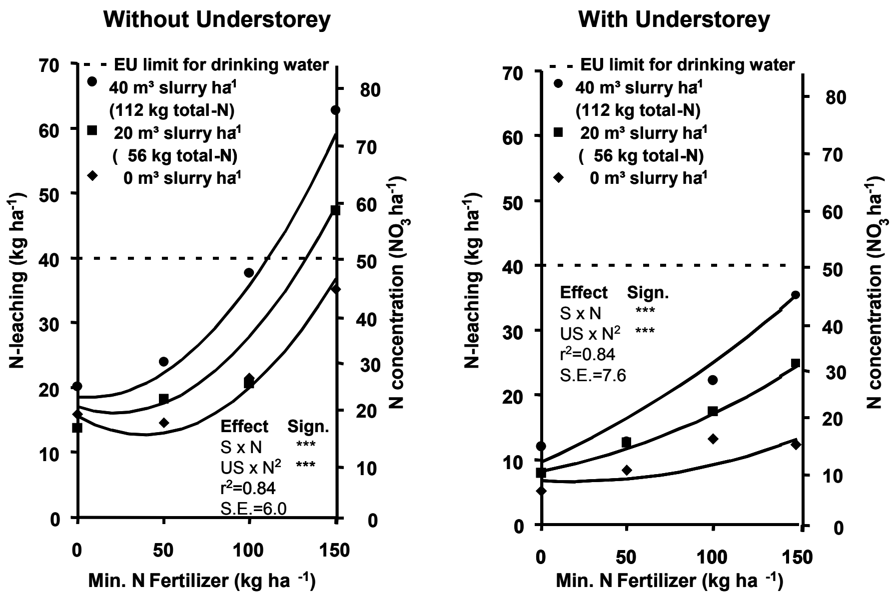

Figure 6. *Nitrate leaching losses (kg N ha⁻¹) under maize for silage (S: slurry; N: mineral N fertiliser, US: understorey) (Büchter et al., 2001).*

Table 5. *Results of analysis of covariants for NO_3 concentration and N load under silage maize grown in monoculture (S: slurry, N: mineral N fertiliser, US: understorey of* Lolium perenne; *mean of leaching period 1998/1999 and 1999/2000).*

	NO_3 concentration	N load
Sign.	S x N ***	S x N ***
Sign.	US x N^2 ***	US x N^2 ***
R^2	0,84	0,84
S.E.	7,6	6,0

Three different scenarios of forage production have been established for such a 'model' farm. Details on the distribution of mineral N among the crops are shown in Table 6:

1. Extensive forage production: low crop productivity and high requirement of concentrates in the diet; 25 m³ slurry ha^{-1}, no mineral nitrogen fertiliser
2. Moderate intensity: 25 m³ slurry ha^{-1} for each crop and an average of 75 kg mineral nitrogen fertiliser per ha of the rotation
3. High intensity: high plant productivity, low requirement of concentrates: 150 kg N ha^{-1} mineral fertiliser, 25 m³ slurry ha^{-1} for each crop

Table 6. N supply by mineral fertiliser and slurry at various intensity levels in the crop rotation trial.

Crop	Mineral fertiliser (kg ha^{-1})	Slurry-N (kg ha^{-1})	Total-N (kg ha^{-1})	Standard values org. + min. N (kg ha^{-1})
1. Extensive forage production				
Hay pasture II	0	75	75	250
Maize silage	0	75	75	150
Triticale	0	75	75	180
N-input	**0**	**75**	**75**	**193**
2. Reduced forage production				
Hay pasture II	100 (50/50/0/0)	75	175	250
Maize silage	25	75	100	150
Triticale	100 (30 *EC21* + 40 *EC31* + 30 *EC39*)	75	175	180
N-input	**75**	**75**	**150**	**193**
3. Intensive forage production				
Hay pasture II	150 (80/40/30/0)	75	225	250
Maize silage	100 (60 and 40 *EC21*)	75	175	150
Triticale	200 (60 *EC21* + 80 *EC31* + 60 *EC39*)	75	275	180
N-input	**150**	**75**	**225**	**193**

Results from this project will provide data for evaluation of arable fodder crop rotations related to permanent grassland and maize cultivated in monoculture in terms of yield and quality of herbage and environmental impacts as well.

5.3.2 Soil quality

Nitrogen release of permanent grassland as a function of climatic, pedological and management conditions differs in a wide range. Schiefer (1984), who examined a wide range of grassland sites in Germany over more than 30 years in terms of nitrogen release without any additional nitrogen fertilisation, showed that there was no decline in nitrogen release during the period of measurements at some sites, whereas soil nutrients in other soils were depleted within a few years. Thus, depending on the starting situation before grassland cultivation, a wide range of consequences in terms of soil quality is possible. On sandy soils in northern Germany, however, it has been shown clearly that conversion of grassland to arable land causes a strong release of soil nutrients. Strebel *et al.* (1988) measured a decrease of about 100 t ha^{-1} C_{org} (-57%), 5-6 t ha^{-1} N_{org} and 1 t ha^{-1} S_t (total mass of sulphur) for a period of 2-4 years after grassland conversion, whereas the quality of the soil organic matter remained unchanged (no changes of the C/N ratio and of the distribution of N_{org} over five N fractions). However, an increase of soil bulk density, a decrease of total pore volume and an acidification push in the soil were observed. Recent results of Ruhe *et al.* (2001) indicate that the proportion of legumes in the sward as well as sward management are also relevant factors for the quantity of nitrogen released after ploughing.

5.3.3 Agronomic performance

In Germany, there is only little recent research on the effects of renovating botanically poorly valued grasslands. Mott & Ernst (1984), however, showed that the agronomic success of grassland renovation in terms of percentage of groundcover by perennial ryegrass is mainly affected by grassland management after resowing or oversowing and less by the technique and date of cultivation.

Conclusions

Grassland cultivation and succeeding implementation of arable fodder crop rotations including maize can be a strategy to enhance the performance of quantity and quality of herbage for high performing dairy cows and to increase nutrient use efficiency in the process of milk production. However, in terms of an holistic approach to evaluate land use systems, gaps of knowledge regarding environmental consequences like nutrient losses or biotic effects have to be bridged in the future.

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6. Grassland renovation in Ireland

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6.1 General Information

6.1.1 Grassland in Ireland

Ireland has a total land area of just over 7 million ha. Agriculture utilises approximately 4.4. million ha (Table 1). The climate is cool, humid and maritime characterised by an evenly distributed annual rainfall and relatively narrow annual temperature range; averaging 4.5°C in winter and 15.5°C in summer. Rainfall varies from 800 mm in the south-east to 2500 mm in the mountainous areas of the west (Lee *et al.*, 1994). Dry lowland mineral soils account for around 0.62 of the agricultural area, while moderately wet mineral soils account for 0.20 and wet impermeable mineral soils for around 0.17 (Coulter *et al.*, 1996). Climate and soils largely dictate agricultural practices with grassland and rough grazing accounting for over 0.90 of agricultural land use. Most dairy, beef and sheep production systems are primarily grass-based with less than 0.10 of total feed inputs coming from non-grassland sources (Lee, 1988). These three enterprises currently account for over 0.70 of gross agricultural output (Table 1). Cereals and non-cereal-root crops (sugarbeet, potatoes etc.) account for approximately 0.07 and 0.02, respectively, of agricultural land use. These tillage-based enterprises tend to be concentrated in the drier regions of the south and east. Although arable crops occupy around 0.09 of farmland, it has been estimated that they consume about 0.15 of the fertiliser N sold annually. Mean fertiliser N input is around 130 kg ha^{-1} year^{-1}, which is around 30 kg ha^{-1} higher than the mean input to grassland (Murphy *et al.*, 1997).

In 1999 there were around 1 575 000 ha (or around 0.36) of farmland being farmed under the Rural Environmental Protection Scheme (REPS). Farmers in REPS receive annual payments of around 150 Euro/ha for a maximum of 40 ha for complying with regulations that include (among others) limiting total N (organic and inorganic combined) inputs to a maximum of 260 kg/ha/year. A further 0.30 of farmland is classified as extensive, involving relatively low stocking rates and fertiliser inputs and many of these farmers are in receipt of non-REPS direct payments for farming extensively (Table 2). These first two classes of farms are principally involved in beef and sheep production with a small proportion of mixed-dairy and dairy enterprises. Around 0.25 of the farmland is farmed intensively and mostly involves dairy and mixed-dairy production. Dairy production enterprises are more highly concentrated in the south-west of the country where relatively high grass production and a long grazing season provides a high-quality low-cost feed for lactating cows. Milk production is highly seasonal with over 0.85 of manufacturing milk being produced between March and October. Typically intensive dairy and mixed-dairy farms are stocked at a rate of 2.5 LSU/ha, producing 5.8 t milk cow^{-1}year^{-1} (Table 3). Fertiliser inputs include 300 kg N/ha and 17 kg P/ha, with 0.44 of the farm harvested for silage in late May and 0.30 of the farm harvested during July. Average quantity of bought-in concentrate is around 725 kg/cow.

Table 1. Land use and livestock numbers in Ireland and value of Gross Agricultural Output (GAO million Euro) of the main Irish agricultural commodities (Central Statistics Office, Cork, 2002).

	Land use		Main enterprises	Number	Value	
	x1000 ha	*Proportion*		x1000	M Euro	*Proportion*
Total Land area	7 027		Dairy cows	1 280		
Forestry	650		Dairy heifers	185		
			Dairy		1 445	*0.34*
Agriculture	**4 404**	***1.00***	Suckler cows	1 175		
			Suckler heifers	105		
Grazing-only	2 325		Beef cattle 2 years +	1 070		
Mowing + grazing	1 228		Beef cattle 1 to 2 years	1 605		
Managed grassland	3 553	*0.80*	Beef cattle under 1 year	1 800		
Rough grazing	465	*0.11*	**Beef**		1 375	*0.33*
Total Grassland	**4 018**	***0.91***	Breeding sheep	4 125		
			Sheep		205	*0.05*
Cereals	283		**Horses**		162	*0.04*
Root crops etc.	81		**Pig & poultry**		414	*0.10*
Set-aside etc.	22		**Cereals**		185	*0.04*
Total Arable	**387**	***0.09***	**Root crops**		144	*0.03*
			Total GAO		4 231	

Table 2. Fertiliser N and P inputs to grassland on different categories of farms (compiled from Murphy et al.*, 1997 and Rath, 2002).*

Farm-type	*Proportion of Land-area*	Fertiliser use	
		(kg N/ha)	(kg P/ha)
REPS	*0.36*	69	8
Extensive	*0.30*	98	13
Intensive	*0.25*	216	16

Table 3. Summary of output and inputs on 108 intensive dairy farms in Ireland.

	Mean	Minimum	Maximum	SD
Dairy as a proportion of LSU on the farm	62.6	24.5	96.0	13.1
Milk production (kg/cow)	5761	4280	7602	621
Milk production (kg/ha)	14423	9287	20764	2110
Stocking rate (LSU/ha)	2.51	1.92	3.29	0.29
Proportion of farm harvested for silage				
May/June	0.44	0.27	0.90	0.11
July/August	0.30	0.10	0.69	0.10
Fertiliser N inputs (kg/ha)	302	163	464	65
Fertiliser P inputs (kg/ha)	17	0	84	12
Concentrates fed (kg/cow)	726	228	3085	364

6.1.2 Grassland Renovation

Each year around 0.03 of Irish farmland (140 000 ha) is sown with grassland seed. It is estimated that around half of this takes place in traditional tillage areas in mixed-arable-grassland enterprises where cereal or root crop production is alternated with grassland-based livestock production. Generally such swards are sown down for at least four years and usually for much longer. The remainder involves grass to grass resowing *i.e.* renovation of permanent grassland (Culleton, *pers. comm.*). Perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) account for virtually all of grassland seed sold for agricultural purposes annually. Negligible quantities of Italian ryegrass (*Lolium multiflorum*) and hybrid ryegrass seed, used for short-term leys of one to four years, are sold each year. It has been demonstrated that, in general, resowing with Italian ryegrass is a less attractive option from an economic point of view than resowing with perennial ryegrass in Ireland (Keating & O'Kiely, 2000a). Sales of other grass species in specialist mixtures, although available on the market, are virtually non-existent. Grassland seed is generally sold as a mixture of perennial ryegrass cultivars with white clover seed included at around 50 g/kg in the seed mixture *i.e.* 30 to 32 kg grass seed plus 1 or 2 kg white clover seed sown per ha. This is more or less the standard seeding rate recommended by retailers and practised on farms, although both Moloney (1962) and Keane (1980) demonstrated that successful establishment can be achieved under experimental conditions at much lower seeding rates. Moloney (1962) obtained the optimum grass and white clover sward at a seeding rate of 13.5 kg/ha and Keane (1980) concluded that grass swards can be successfully established at seeding rates of 15 to 20 kg/ha. Higher seeding rates are generally used at farm level to reduce risk of failure due to sub-optimal seedbed conditions, excessive sowing depth, drought etc.

6.1.3 Legislation

There is currently no legislation or any legislation pending in relation to the renovation of grassland. Cultivation of riparian zones and lake-side strips is not permitted in designated areas. In fact, grassland renovation with the objective of increasing the white clover content of pastures is recommended on farms managed to REPS standards.

6.2 Farmer's situation

6.2.1 Grassland renovation on extensively managed farms

Most Irish grassland consists of indigenous permanent swards of diverse botanical composition (O'Sullivan, 1982; Eakin, 1995). This is hardly surprising given the low intensity of production on most farms (Table 2). Extensively managed grassland farms tend to be more concentrated in northern and western regions, typified by high rainfall (>1100 mm/year) and poorer soil types: moderately wet mineral, wet impermeable mineral and peat soils. The sowing of grassland seed on such farms usually only takes place following land reclamation (land drainage etc.). In the far north-west of Ireland the average accumulated soil moisture deficit between May and August is 0 mm and does not exceed 25 mm in the north-western half of the country (Collins & Cummins, 1996). Reclamation procedures are favoured by drier soil conditions and there is generally a rush of land reclamation during exceptionally dry summers. This is followed by a marked increase in sales of grassland seed during the ensuing autumn (Culleton, *pers. comm.*); land is sown with perennial ryegrass and white clover once the reclamation operations are completed.

Collins & Murphy (1979) reviewed the results of a wide range of field experiments carried out in Ireland during the 1950's, 1960's and early 1970's and concluded that under grazing management, animal production from sown perennial ryegrass swards was rarely greater than from swards composed of indigenous species. They pointed out that attention to soil pH and fertility combined with proper drainage and grassland management were more important factors in determining productivity than botanical composition. This conclusion is supported by more recent work by Mullen *et al.* (1974; 1978), Culleton (1989) and Keating & O'Kiely (2000c) who demonstrated, under low to moderate fertiliser N inputs, that the cost of replacing the old sward by a sown perennial ryegrass sward could not be economically justified. For example, Culleton (1989) compared an old permanent grassland sward with a sown perennial ryegrass sward under grazing management. Both the old and the sown perennial ryegrass swards received applications of lime, P and K fertilisers and moderately high fertiliser N inputs of 250 kg/ha/year. It was found that grazing the sown perennial ryegrass sward improved animal performance in the initial years. However, this advantage had diminished by the third year of the experiment. This was contrary to the fact that the sown perennial ryegrass sward (cultivar: Vigour) remained the dominant species at around 0.97 during the experiment. On the other hand improved management of the old permanent pasture sward, under grazing, increased the perennial ryegrass content while decreasing the content of *Agrostis* species (Table 4). Bailey (1997) also pointed out the importance of maintaining optimum soil pH (6.0 to 6.5) and N fertilisation to promote the perennial ryegrass content of permanent grassland swards.

Table 4. *Changes in the botanical composition of an old permanent grassland sward during three years of improved management (Culleton, 1989)*

Year	Perennial ryegrass	Agrostis species	Poa trivialis	Holcus lanatus	Others
1985	0.04	0.41	0.32	0.14	0.10
1986	0.19	0.33	0.30	0.09	0.09
1987	0.32	0.26	0.29	0.05	0.09

The gradual replacement of sown perennial ryegrass by indigenous grass species has been recorded in a number of other experiments. Keane (1982) recorded that the perennial ryegrass content of sown swards had declined to 0.52 over a five-year period. Collins & Murphy (1979) noted in experiments with sown perennial ryegrass swards, that indigenous grasses had come to dominate the sward after a period of between two and four years after sowing, except where very high fertiliser N (e.g. 412 kg/ha/year) was being applied. Generally speaking the grasses that came to dominate the swards were *P. trivialis* and *Agrostis* species. Bailey (1997) made the case that many indigenous grasses have evolved under conditions of low soil fertility. Therefore indigenous species, such as *Agrostis stolonifera* may be much more efficient at competing with the microbial biomass for soil mineral N than perennial ryegrass. Most commercial perennial ryegrass cultivars have been selected and tested under conditions of high soil fertility and therefore may be less competitive in extensively managed swards.

Collins & Murphy (1979) pointed out that there are distinct differences in the desirability of various indigenous grasses and in the grassland management practices that favour the abundance of various species in swards. Controlled grazing management, along with optimum applications of lime and P and K fertilisers can improve the botanical composition and productivity of swards. This may result in swards dominated by desirable species such as indigenous perennial ryegrass, white clover and *Poa trivialis* and other species of intermediate value such as *Dactylis glomerata* and *Holcus lanatus*. For example, *Poa trivialis* tends to become dominant and has good agronomic potential under grazing (Collins & Murphy, 1979) and also tends to be better than most other indigenous species in terms of silage preservation, although poorer than perennial ryegrass in this aspect (Wilson & Collins, 1980). On the other hand, *Agrostis* species tend to become dominant in swards primarily harvested for silage (Collins & Murphy, 1979). These species, along with *Agropyron repens* and *Festuca Rubra* are considered to have poor agronomic potential under grazing (Collins & Murphy, 1979) and *Agrostis* species and *F. rubra* also resulted in a very high proportion of poor quality silages (Wilson & Collins, 1980).

Therefore, in extensively managed enterprises (such as extensive beef production), there is not a good case for replacing an existing sward by a sown perennial ryegrass swards unless the resowing operation is part of land reclamation or where there is very poor botanical composition. Generally it is not recommended to replace an extensive grassland sward unless the perennial ryegrass content is less than 0.20 (Collins & Murphy, 1979) and the content of *Agrostis* and other undesirable species exceed 0.30. In addition to this recommendation, on-going work in Ireland (Teagasc and University College Dublin) is examining the potential of non-destructive methods of introducing white clover into extensively managed pastures as a means of improving sward nutritive value and reducing fertiliser N costs.

6.2.2 Grassland renovation on intensively managed farms

Well-managed home-produced grazed grass is by far the cheapest form of feed for ruminants in Ireland (O'Kiely *et al*., 1997). Although grass-silage is a more expensive feed than grazed grass, it provides a substantial amount of ruminant feed requirements during the winter-housing period. This is partly because it can be an economically competitive feed in its own right and partly because harvesting of grass-silage during the grazing season is usually a necessary component of maintaining the nutritive value of grazed swards (O'Kiely *et al*., 1997). Furthermore, they pointed out that it is critical that high yields of grass for ensilage are achieved at each harvest to maintain the economic attractiveness of grass-silage. This is particularly important where grass crops are harvested by contractors charging on a per-hectare basis, as is primarily the case in Ireland. Therefore there is a better case for resowing swards that will subsequently be used primarily for silage production than for grazing on both extensive and intensively managed farms.

Culleton (1989) demonstrated that under a simulated three-harvest silage harvesting regime and receiving fertiliser N inputs of 250 kg/ha/year, the sown perennial ryegrass sward consistently out-yielded the old permanent pasture during the three years of the experiment: 13.6 compared with 10.1 t DM/ha/year. The sown perennial ryegrass sward also had significantly better *in vitro* digestibility. The magnitude of difference in herbage yield between the two swards had declined during the experiment. Yields of the sown sward declined while yields of the old sward tended to increase over the three years. The perennial ryegrass content of the sown sward diminished from 0.99 in the first year to 0.75 in the third year. The perennial ryegrass content of the old sward remained low at around 0.04.

Under intensive silage production harvested four-times/year and receiving 430 kg N/ha/year, Keating & O'Kiely (2000a) compared a previously well managed old permanent sward with a sown perennial ryegrass sward. The old sward was dominated by *Poa trivialis* (0.33) and *Agrostis* species (0.31) along with indigenous *L. perenne* (0.15) and diverse other grassland species. They found no detectable difference in grass production between the two swards over the three years of the experiment; the old sward yielded 13.5 t compared with 13.8 t DM/ha/year from the sown perennial ryegrass sward. In two years of the experiment, grass from both swards was ensiled separately and fed to growing cattle. In the first year neither silage DM intake nor carcass gain were significantly affected by sward type. However, in the second year cattle offered silage from the first harvest (harvested in late May) of the old permanent sward had significantly lower intake and carcass gain than those offered the silage from the comparable harvest of the sown perennial ryegrass sward. Overall they concluded that carcass output per ha was higher for the sown perennial ryegrass sward. This was attributed to improved silage DM intake and better efficiency of utilisation for carcass gain of silage DM consumed for perennial ryegrass than old permanent pasture.

In the same series of experiments, Keating & O'Kiely (2000b) recorded that the old permanent sward had lower *in vitro* digestibility, lower water soluble carbohydrate (WSC) concentration but similar lactic buffering capacities to the sown sward. Wilson & Collins (1980) also recorded lower WSC concentrations for an old permanent pasture sward and most of its constituent grasses than for perennial ryegrass. Furthermore, in both experiments silages produced from the old permanent grassland tended to be less well preserved than that made from perennial ryegrass.

Management for the production of grass-silage involves long growth intervals that tend to thin perennial ryegrass swards (Culleton *et al.*, 1991). Lodging of the sward and poor application of slurry resulting in open patches in the sward further reduces perennial ryegrass content. This favours the ingress of undesirable grasses such as *Agrostis* species (Collins & Murphy, 1979) and broad-leaved weeds such as *Rumex obtusifolius*, which tend to be a problem of intensively managed silage swards in Ireland (Humphreys *et al.*, 1997; 1999). In fact, one of the questions most frequently put to advisors from farmers concerns the best method of eliminating *R. obtusifolius* infestations from swards. The general experience among advisors is that, while several recommended selective herbicides will knock back *R. obtusifolius* infestations, no selective herbicide will permanently eliminate well-established populations. Therefore, where serious infestations are getting out of control (ground cover greater than 0.15 shaded by *R. obtusifolius*), one recommendation is to kill off the whole sward with a non-selective systemic herbicide such as glyphosate and to re-sow the pasture. Application of glyphosate during late July, August or early September, following defoliation during the summer to ensure that the *R. obtusifolius* foliage is actively growing at the time of application, is considered to be very effective means of killing off old *R. obtusifolius* rootstocks. This can be tied in with grassland resowing operations (see below).

6.2.3 Criteria used for deciding when to re-sow swards

Resowing swards is an expensive operation (Table 5). The justification for resowing a sward depends on a financial benefit accruing from an increase in productivity. For intensive dairy production, Teagasc specialist advisors recommend replacing grazing swards when the perennial ryegrass content is less than 0.40 and the content of *Agrostis* and other undesirable species exceed 0.30. This is partly because sown perennial ryegrass swards will respond better than permanent pasture to high N fertilisation when soil P, K and pH are optimal and when the soil is well drained and the pasture is well managed (Mullen *et al.*, 1978; Collins & Murphy, 1979). The other aspect is the relatively high nutritive requirements of intensively managed lactating dairy cows, which have increased substantially in the past decade (Buckley *et al.*, 2000). At farm level, practical criteria used for deciding whether to replace an existing sward involves monitoring milk production and protein concentration in the milk, or noting changes in cattle behaviour, from paddock to paddock. Swards with lower nutritive value will generally instigate a dip in milk output and/or composition and cattle will be less content and will not graze-out well a poorer quality sward.

Teagasc specialist advisors recommend resowing swards used primarily for silage production on a fairly regular basis (every 5 to 10 years) depending on the condition of the sward (although such swards should be rotated between grazing and mowing management as much as possible). Similar to above, it is recommended that silage swards are replaced when the perennial ryegrass content is less than 0.40 and the content of *Agrostis* and other undesirable grass species is greater than 0.30. Furthermore, resowing is recommended when greater than 0.20 of the surface area is exposed as bare patches in the sward or when over 0.15 of the surface area is shaded by *R. obtusifolius*. Also, silage quality is routinely tested on many Irish farms for the purpose of determining requirements for supplementary feeding. This data on silage quality, combined with other aspects, can provide an indication of the need to re-sow a particular sward.

Table 5. The costs of resowing grassland (Euro/ha).

Input	Conventional Ploughing	Minimum cultivation 2 runs power harrow	Minimum cultivation single-pass system
Glyphosate + spraying	60	60	60
Lime + spreading	83	83	83
Ploughing + levelling	56 + 16	0	0
Power harrow/rotospike/rotovator	48	95	0
Sowing	25	25	0
Single-pass cultivator & seeder	0	0	125
Grass & white clover seed	95	95	95
Rolling	20	20	20
Fertiliser + spreading	77	77	77
Total costs	480	455	460

*Additional costs can include 20 Euro/ha for post-emergence herbicide, 16.5 Euro/ha for slug pellets and 11.5 Euro/ha for insecticide for control of frit fly larvae (*Oscincilla frit*).*

6.2.4 Grassland renovation: timing and methodology

The timing of, and methods used for resowing depend on the particular mix of enterprises on a farm. In mixed-arable farms, under-sowing of perennial ryegrass and white clover to spring barley or arable silage crops is often practised. An advantage associated with this method of resowing is that area aid payments amounting to 382 Euro/ha can be claimed on the main-crop, once the field is 'eligible' for these payments, hence, this is only practicable to mixed-arable farms. These payments can go a long way towards meeting the costs associated with resowing. Furthermore, under-sowing generally involves minimal loss of production of the main crop. However, the success of under-sowing in terms of the establishment of the perennial ryegrass and white clover sward is not always satisfactory at farm level, especially where there has been lodging of the main-crop etc. Also, under-sowing involves a compromise between the best post-emergence herbicides for the main crop and that for the under-sown crop, often to the detriment of white clover. Therefore under-sowing is not an ideal approach on farms where white clover is considered important. Another approach on mixed-arable farms is to introduce perennial ryegrass and white clover seed by minimal cultivation following harvest of winter barley in late July or August. This can involve spraying the barley crop with glyphosate about two weeks prior to harvest. After harvest the straw is baled and removed and perennial ryegrass and white clover seed is sown directly into the barley stubble using single-pass cultivator & seeder. This is a comparatively cheap method of sward establishment and is considered to be a highly successful approach at farm level (e.g. Mullen *et al.*, 1978).

Grass to grass resowing generally takes place during the period of mid-July to mid-September when there is potential for surplus of grass supply of most farms. Although April is considered to be an ideal month to undertake resowing, there is rarely an opportunity to do so. On most farms there are great demands placed on grass supply during this time of the year to meet requirements for grazed grass and for silage production in the run-up to the main silage-harvest period. On most farms, the main crop of grass for ensilage is harvested between mid May and mid June. On extensive farms, stocked at less than 2 LSU/ha, a second crop is rarely harvested, although subsequent surpluses in grass supply are removed as baled silage. On more intensive farms a second crop of silage is usually harvested during July (*e.g.* Table 3). Therefore on most farms the most likely opportunity to re-sow grassland generally occurs after mid-July and before it is necessary to build up a surplus of grass during September for extending the grazing season into the late autumn and winter.

There are two main methods of grass to grass resowing. The more traditional approach involves ploughing and tilling, whereas the alternative involves shallow cultivation. Ploughing (to between 200 and 250 mm) and tilling is recognised as a very reliable method of resowing. However, it is only recommended where it is necessary to level the ground, for example, following land drainage, or to reduce compaction, for example, in fields traversed repeatedly by heavy silage-making machinery, mainly because it is more expensive than shallow cultivation (Table 5). Furthermore, Mullen *et al.* (1978) demonstrated that shallow cultivation resulted in swards that were equally as productive as swards produced by traditional ploughing and tilling operations.

Shallow cultivation involves killing off the existing vegetation with glyphosate, especially where *R. obtusifolius* infestation of the existing sward is a problem. After 5 to 10 days the pasture is removed by harvesting for silage or by grazing close to ground level. Grazing is usually followed by a mechanical defoliation (topping). It is recommended that 2 to 5 t/ha of ground limestone (depending on requirements) is applied to the soil surface to overcome surface acidification and potential allelopathic effects associated with release of residues by the decaying thrash and stubble. After two or three weeks, the soil surface is cultivated, either once or twice, to a depth of approximately 50 mm using a power harrow or similar implement. The seedbed is then rolled and perennial ryegrass and white clover seeds are applied to the resulting firm seedbed. Drilling-in and burying the seed is not recommended. There is usually sufficient moisture to ensure successful germination and establishment; drought conditions are not a regular occurrence during the autumn in Ireland and can usually be avoided. It is generally recommended to roll the seedbed following resowing to ensure good seed to soil contact. An alternative to this approach is to replace the power-harrow and seeder by a single-pass cultivator & seeder. As above, it is recommended with this approach that the perennial ryegrass and white clover seed be applied to the soil surface and not drilled-in.

Other advantages associated with shallow cultivation are:

(1) It is suitable for shallow soils or where the topography is unsuitable for ploughing.

(2) Relatively immobile soil nutrients such as P tend to be concentrated at the surface of permanent grassland soils (Humphreys *et al.*, 1998). With shallow cultivation they are retained at the soil surface rather than ploughed down where they are not readily assessable to establishing seedlings. High soil P concentrations in the vicinity of perennial ryegrass seeds are important to promote rapid establishment (Culleton *et al.*, 1990).

(3) Stones are not brought to the surface.

(4) Better aggregate stability and trafficability and lower poachability in the early years following resowing (Mullen *et al.*, 1974). In fact, Mullen *et al.* (1974) found that soil, following sowing of perennial ryegrass using shallow cultivation, had similar aggregate stability to that under undisturbed permanent grassland, whereas soil that had been ploughed had higher bulk density and reduced aggregate stability and was more liable to poaching by grazing cattle. Ploughing tended to disturb and bury the strong well-aggregated surface soil, while the soil under the shallow cultivation treatment retained the desirable structural features developed at the soil surface by the preceding grass crop. Hence, Mullen *et al.* (1974) concluded that from the perspective of maintenance of soil structure, shallow cultivation is better than ploughing as a method of soil preparation for pasture establishment.

It is generally recommended that sowing operations should ideally be completed before the middle of August and by the middle of September at the very latest. Mid August is preferred because it will favour the establishment and survival of white clover over the following winter. Furthermore, sowing before mid August allows the opportunity to use a (clover-safe) post-emergence herbicide to hit emerging *R. obtusifolius* seedlings before they develop a taproot and become more resistant to the less-expensive selective herbicides. Another reason is that it allows application of fertiliser N to coincide with and promote tillering before it gets too late into the autumn for such applications. Furthermore the re-sown sward will increase grazed grass supply by late September and October, thereby contributing towards extending the grazing season and reducing winter-feed costs. Grazing before the winter is considered desirable to help thicken the sward for the following spring. However, in practice, most autumn resowing does not take place until late August and September or even early October in some instances. Sowing perennial ryegrass and white clover seed later than mid September is not recommended because it can result in comparatively poor establishment and increased seedling mortality, reducing tiller densities and production during the following spring (Culleton *et al.*, 1992).

Late-heading perennial ryegrass cultivars (mean heading dates between early and mid June) are generally recommended for most farming situations in Ireland. They tend to provide leafier growth during midseason improving grass DM intake and milk production compared to intermediate-heading cultivars (mean heading dates between mid and late May) (O'Donovan, 2001). They also tend to be more persistent and produce denser swards (DAFRD, 2002). This may be advantageous on wet soils that are prone to poaching damage. In addition, although tending to be lower yielding during the period between mid May to mid June, late cultivars maintain higher nutritive value and hence provide greater flexibility with regards to silage harvesting date during this period (Humphreys & O'Kiely 2001; 2002). These advantages are reflected in seed sales (Culleton, *pers. comm.*); around 0.60 of seed sold in Ireland are of late perennial ryegrass cultivars.

6.2.5 Economic costs/benefits of grassland renovation

It is possible that the direct costs associated with resowing could exceed 500 Euro/ha (Table 5). This does not include the indirect cost arising from the loss of production as a result of taking land out of production during the resowing process. In grass to grass resowing during the autumn, as outlined above, this could amount to a loss of around 2 t DM/ha, which, costing around 50 Euro/t DM to produce, equals 100 Euro/ha. However, the replacement cost of this grass as a feed could be much higher, costing at least 100 Euro/t DM or adding at least 200 Euro/ha to the overall costs of resowing. However, it is highly unlikely that a rational farmer will attempt to re-sow grassland unless a surplus of grass supply already exists on the farm. Furthermore, it can reasonably be argued that the inputs of fertiliser and lime, amounting to 160 Euro/ha (Table 5), are an integral part of maintaining the soil fertility on the farm and their application to the sward would equally be necessary in the absence of the resowing operation. One way or another, the minimum costs that can be attributed to grass to grass resowing are likely to amount to around 300 Euro/ha. In this context, the cost-advantages associated with under-sowing are clear once good establishment of the sown perennial ryegrass and white clover is achieved. The only additional cost associated with under-sowing is that associated with the perennial ryegrass and white clover seed and perhaps a relatively small additional cost associated with using a 'clover-safe' rather than a 'non-clover safe' post-emergence herbicide.

On all-grass farms, the chief determinant of the true cost of replacing a sward is how effectively this cost can be spread over time. It is clear that renovating 0.10 of the farm every 10 years (30 to 40 Euro/ha/year) is less costly than renovating 0.20 of the farm every 5 years (60 to 80 Euro/ha/year). In the first situation an overall increase of 0.10 in grazed grass supply per year over the 10 years that is directly attributable to resowing would be necessary to cover costs, *i.e.* approximately 1 t DM of grazed grass. This is unlikely to be the case where swards were previously well managed, but may well be the case where the existing swards are of very poor botanical composition. Hence, resowing in Ireland is often associated with land reclamation. In the second scenario a 0.10 increase in grass yields for ensilage per year over the 5 years would cover costs, *i.e.* approximately 1.32 t DM of additional grass harvested for ensilage, allowing 0.25 losses associated with ensiling etc., provides approximately 1 t of silage DM valued at 100 Euro. It is possible that this would be the case; Mullen *et al.* (1978) showed increases in grass yields in four years out of five and Culleton (1989) showed substantial increases in grass yields for ensilage over the three-year period of the experiment. Furthermore, although Keating & O'Kiely (2000a) did not show an increase in grass yields by replacing an old sward by a sown perennial ryegrass sward, there were other advantages associated with the sown sward that justified resowing. These included higher *in vitro* digestibility and improved ensilability resulting in improved silage DM intake and better efficiency of utilisation for carcass gain of silage DM consumed. There are also the other aspects such as elimination of *R. obtusifolius* infestation or reduction is soil compaction etc.

Most of the advantages associated with resowing are dependent on the quality of the existing sward relative to the success of the resowing operation along with the extent to which the renovated sward can be maintained and utilised for livestock production and the value of the saleable produce. In reality, swards on extensively managed grassland farms in Ireland are rarely renovated. However, on more intensively managed farms, swards are probably replaced about once in every 20 years on average. Resowing operations are much more likely to be undertaken when a surplus of grass is available on the farm, hence not incurring a replacement cost for the loss of grass production, and when weather and soil conditions are suitable during the autumn period of the year. This combination of events may only occur in one year out of four on average. Swards that are used predominantly for silage production are generally targeted for resowing because these are more prone to deterioration *i.e.* loss of perennial ryegrass and invasion of *Agrostis* and other undesirable grass species and *R. obtusifolius*, which reduces the productivity and ensilability of swards. Furthermore, resowing silage swards is also more likely to show an economic benefit because of the comparatively high costs associated with harvesting and feeding of grass-silage (Keating & O'Kiely, 2000a).

6.3 Research: state of the art

6.3.1 Nutrient cycling, soil quality and emissions to the environment

It has been pointed out above P tends to be concentrated in the upper layers of permanent grassland soils (Humphreys *et al.*, 1998). One of the advantages of shallow cultivation is that this P is retained at the soil surface rather than ploughed down where it is not readily assessable to establishing seedlings. However, very high soil P concentrations in the surface layers of soils, for example, on grassland in the vicinity of pig units, may predispose to loss of P in surface runoff depending on soil infiltration characteristics and catchment hydrology (Sharpley & Rekolainen, 1997). It is possible that where there are high P concentrations in the surface layers of permanent grassland soils that ploughing these surface layers down may help to reduce risk of P loss in surface runoff and increase the capacity of the soil for further additions of pig slurry. However, this might only be a short-term solution to this problem.

It is much more likely that ploughing of grassland will increase nutrient losses to the environment, especially losses of N and C. In a study of the organic C content of mineral soils under pastureland in Ireland, Brogan (1966) reported that the average C content was 0.053 and ranged from 0.020 to 0.178. The average N content was 0.0047 and the average C:N ratio was 11.3. Highest soil C contents tended to be associated with old permanent pasture swards. McGrath (1988) attributed real differences in the C content between soils (other than redistribution associated with ploughing and tilling) to the selection of lighter soils for cultivation and to the subjection of the sward to microbial attack after ploughing. The ploughing of grassland can cause a dramatic increase in the amount of C and N released due to increased mineralisation of soil organic matter (*e.g.* Gately, 1975a,b). Ryan (unpublished, *pers. comm.*) in a lysimeter study across a range of soil types, recorded nitrate-N leaching losses following the cultivation of grass swards. Prior to cultivation the grass swards had received annual inputs of 300 kg fertiliser N plus 120 kg slurry N/ha during the previous two years. During these two years nitrate-N leaching losses of less than 5 kg/ha/year were recorded (Ryan & Fanning, 1996). However, the lysimeters were cultivated and sown with perennial ryegrass and the equivalent of 50 kg fertiliser N/ha was applied during resowing. Across the range of soil types the mean (± SD) quantity of N leached following resowing was 244 ± 54 kg/ha and mean (± SD) nitrate-N concentration in leachate was 30 ± 6 mg/litre. Large increases in nitrate leaching have also been recorded following ploughing of grassland under field conditions (Bartley *et al.*, 2002). Furthermore, in a regional-scale study, Neill (1989) concluded that the ploughing of agricultural land was the principle factor affecting the concentrations of nitrate in rivers in the south-east of Ireland. It is possible that the recommended practice of shallow cultivation for grassland renovation most often used for grass to grass resowing in Ireland may include the benefit of lower leaching losses, although this has not been examined. Six *et al.* (2001) outlined the beneficial effect of minimal tillage operations compared with conventional ploughing in terms of decreasing soil N and C mineralisation and hence the likelihood of reducing nitrate-N leaching losses to surface and ground waters and perhaps CO_2 emissions to the atmosphere.

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7. Grassland resowing and grass-arable rotations in the United Kingdom: agricultural and environmental issues

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7.1 General information

7.1.1 Key figures on intensity of grassland use

The United Kingdom (UK) comprises England, Wales, Scotland and Northern Ireland (NI) with a combined land area of 24 million ha, 75% of which is in agricultural use, but with the agricultural workforce representing only <1% of the population. Of the total UK land area, 13.1% is in cereals, 4.2% supports other crops (oilseed rape, sugar beet, potatoes, hops, linseed), 1.5% produces fodder crops (peas, beans, maize, etc.) and more than half (*ca.* 52%) is under grassland (source: MAFF, 2000a).

Land used for rough grazing and a proportion of the swards that have not been reseeded in the last 20 years will rarely be fertilised, but most enclosed grassland will receive nitrogen (N) and also some phosphorus (P) and potassium (K,) particularly if the swards are to be cut. Table 1 shows overall rates applied to UK grassland for the previous 5 years.

Table 1. Mean application of nutrients (kg ha^{-1}) as fertiliser to all grassland in UK 1996-2000.

	1996	1997	1998	1999	2000
N	115	123	109	110	99
P_2O_5	23	25	21	20	20
K_2O	30	35	29	28	26

Source: The British Survey of Fertiliser Practice, 2000

Total N applied to grassland dropped significantly in 2000, due to a fall in compound N use, whereas straight N use has changed little. Overall N use had been increasing prior to 1969, but from the mid 1980s, showed a downward trend due to reductions in livestock numbers in the beef, sheep and dairy sectors and a reduction in N fertiliser recommendation in the early 1990s. In NI, N and P applications were on average 15-20% higher and K applications were similar to the UK as a whole, but fertiliser use had otherwise remained fairly stable, although a sharp fall of 15 kg N ha^{-1} was recorded in 2001.

The rates of N use on some intensive systems can be much higher than would be suggested by the UK averages shown in Table 1. Table 2 shows the maximum recommended rates for some intensive grassland management systems (MAFF, 2000).

Table 2. Examples of annual N inputs to grassland (kg ha^{-1}), according to UK fertiliser recommendations (MAFF, 2000). These represent maximum N rates for high stocking densities.

Management	Soil nitrogen supply status		
	Low	Moderate	High
Grazing – dairy cows (28 day cycle)[a]	380-460	340-420	300-380
Grazing – beef/sheep[a]	330-410	290-370	250-330
68-70D silage (4 cuts/year)[b]	420	380	340
64-67D silage (3 cuts/year)[b]	370	330	300

[a] *upper figure relates to sites of 'very good' grass growth (deep soils and high rainfall)*
[b] *reduce applications below this if later silage yield is restricted by drought*

Output from grassland in standard terms has not been evaluated recently, but the average annual utilised metabolizable energy (UME) output for UK dairy farms, surveyed in 1975-7 (Forbes *et al.*, 1980), was 44 GJ ha^{-1} and took into account the total area of all the fields on the farms (including rough grazing). A more recent estimate, obtained from 5 profitable farms in SW England, averaged 72 (range 47 – 91) GJ UME ha^{-1} (Peel *et al.*, 1988). Estimates for NI are likely to be about 45–50 GJ ha^{-1}, however the potential output from grass from an intensive dairy can be much higher and is estimated to be approximately 140 GJ UME ha^{-1} (at the Agricultural Research Institute at Hillsborough). UK stocking rate is about 0.9 LSU ha^{-1}, or about 1.5 (1.6 in NI) LSU ha^{-1} for enclosed land, i.e. if rough grazing (range land) is excluded. Grazing, other than on dairy farms, where the system is mainly rotational (with some continuous stocking), is flexible, often involving periods of set stocking, or a type of 2–3 field rotation.

7.1.2 Key figures on the intensity of grassland cultivation

The 12.6 million ha of UK grassland includes permanent and semi-permanent grassland (44%), rough grazing (36%) and common land (10%), but 1.2 million ha (*ca.* 10% of the total grassland) is in leys which are under 5 years (source MAFF, 2000a). This means that in any one year, approximately 20% of these leys, on average, would be ploughed and reseeded, amounting to about 245,000 ha ploughed grassland per annum. However, this represents only the baseline level, since some short-term leys of 2-3 years (no data available) could have been ploughed more frequently and would be included in this category. In the absence of more recent data from farm surveys, another indication of the extent of grassland resowing can be obtained from the sales of grass seeds (Figure 1), although this data will also include non-agricultural uses, such as domestic and amenity grasslands and provides no detailed information about the renewal of grassland and leys in rotations. From the mid 1960s to the present, perennial ryegrass seed sales have been fairly consistent and using average sowing rates would suggest that the areas of grass resown annually amount to some 350,000 ha. Thus, the average of these two estimates suggests that about 300,000 ha of grassland is resown annually in the UK. Sales of Italian ryegrass seed have fallen during the same period (Figure 1), reflecting the decline in the use of short-term leys in arable rotations in preference for maize, which unlike grass, attracts subsidy payments. Overall, the total area of enclosed land in the UK which is <5 years has declined over the last two decades: 30% in 1977, down to 18% in 1999, confirming the move away from short-term leys towards older swards, infrequently ploughed for renewal, or renovation of damaged swards. The total area under cultivation (grass + arable) in the UK represents 20% (5 million ha) of the agricultural land. Not all of this will be ploughed annually, as minimal tillage, inter-cropping and catch crops will require less cultivation, if previously ploughed land is used.

In NI, there are about 140,000 ha grassland which are <5 years old, 700,000 ha >5 years and 154,000 ha rough grazing. The cropping area is 51,000 ha. About 35,000 ha of grassland are reseeded annually, representing 4% of the total grassland area.

Organic farming is rapidly increasing in importance, with 3.2% of UK agricultural land classified as organic, or in conversion to organic and farmed by 3691 producers. In 2000-2001, the area in organic farming increased by 33% from 416,000 ha to 552,500 ha, of which over 90% was recorded as grassland (Source: Soil Association 2001 Organic Food & Farming Report).

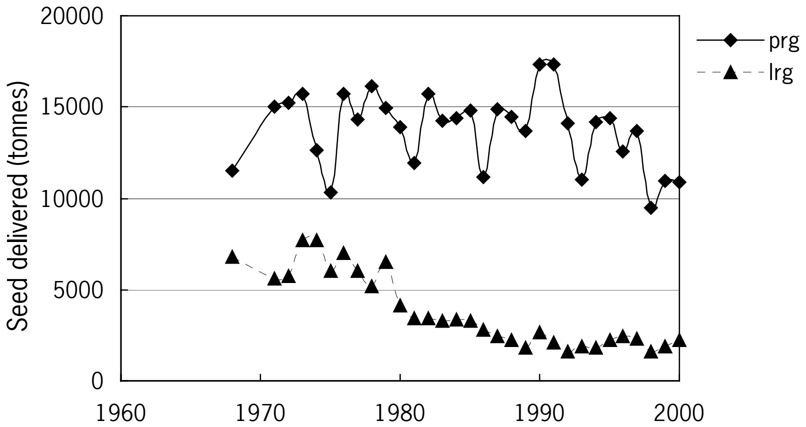

Figure 1. *Ryegrass seed deliveries in UK. Key: Perennial ryegrass (prg); Italian ryegrass (Irg).*

7.1.3 Is there legislation with respect to grassland cultivation?

There are existing regulations preventing cultivation in Sites of Special Scientific Interest (SSSIs), protected under the Wildlife and Countryside Act 1981, or the Conservation (Natural Habitats etc.) Regulations, 1994 which would also include National Parks. In the 'Habitat Scheme, Water Fringe Areas', farmers were banned from ploughing, levelling, or reseeding grass together with all general agricultural management. In the UK, 72 major areas (600,000 ha in total) have been designated as Nitrate Vulnerable Zones (NVZs), though this is under review and the total area designated as NVZs will increase substantially. Within these areas, fertiliser use is regulated and inputs should be adjusted specifically to allow for N release after ploughing intensively grazed grassland (NVZs, 2001). This advice is reinforced for all grassland in the Water Code (voluntary) which recommends that N leaching is reduced by minimising soil disturbance (especially for ploughing permanent pastures) and establishing a green cover before October (Water Code, 1998). Further legislation has recently come into force (February, 2002) in the form of Environmental Impact Assessments (EIA) to consider the potential environmental effects of projects which involve change of land use. The legislation has been extended by bringing in EIA procedures for projects for the *use of uncultivated land or semi-natural areas for intensive agricultural purposes*. These regulations now implement specific European Community requirements. Land would be considered to be uncultivated if it had less than 25-30% of ryegrass (*Lolium* species) and/or white clover (*Trifolium repens*), or other sown grass species indicative of cultivation, where cultivation includes ploughing, rotavating, harrowing, tining, discing and reseeding.

7.2 Farmer's situation

7.2.1 What causes the need for grassland cultivation?

Unless grazing swards are badly poached and/or severe soil compaction has occurred, reseeding is restricted to ageing swards cut for silage. Falling yields was given as the main reason for conventional farmers to consider reseeding in a survey of 95 fields carried out in 1977-1978 (Haggar, 1979) and 58% of the farmers interviewed had a policy of replacing old grass leys with new, every 5 years. However, there was some suggestion that the decisions were being made without firm evidence of deteriorating productivity and reseeding was being done as a routine, or based on the appearance of the sward. Agricultural economists work on the principle that a cut sward will be renewed every 7 years and a grazed sward every 15 years. In NI, of the 40,000 ha of cereal sown, estimates are that about 6,000 to 8,000 ha are undersown either as a break in a rotation or as a nurse crop for establishing grass. For organic farmers and others in mixed systems it is the need to release N and other nutrients (essentially P and S) that determines the strategy. However, leys and 'permanent' grassland at Coates Farm of the Royal Agricultural College were ploughed because of a decline in profitability in the dairy sector. Thus, the Common Agricultural Policy (CAP), global markets and the like can greatly affect grassland ploughing.

7.2.2 Which criteria does the farmer use for his decision for grassland cultivation?

As stated above, the reasons are not always clearly defined, but poor quality grass may be insufficient to sustain maximum production per animal. The decision, therefore, to renew a grass sward is usually based on the appearance of weed grasses e.g. *Poa* spp., or *Agrostis stolonifera* in a silage sward, or a heavy infestation of dicotyledonous weeds, such as docks, in a grazing or silage sward. Reseeding may also be undertaken to repair swards that have suffered severe damage. Improved herbage quality enables the farmer to reduce his use of supplements. The main herbage quality criteria were identified (Wheeler & Corbett, 1989) as high dry matter digestibility, easy comminution into smaller particles, high non-structural carbohydrate content, high protein content and high sulphur amino acid content (mainly wool production).

7.2.3 Which methods are used for grassland cultivation and at what time of the year is it normally performed?

Most cultivation is carried out in late summer, or early autumn. Often (particularly on heavier soils), the old sward would be killed with a herbicide, cultivated (e.g. rotary harrow) to break down the turf and ploughed in. Further cultivations would be used (if needed with heavier soils) to produce a finer tilth and then rolled to consolidate the seedbed. Very few grass swards are established by direct drilling, or minimal cultivation in Northern Ireland. Usually the old grass is ploughed and reseeded. Traditionally, and often with good reason, direct sowing was carried out in autumn to reduce weed infestation while grass established by undersowing was in spring. This is still the case. However, contrary to the conventional wisdom that most of our grass is established by undersowing, the statistics and seedsmen's estimates would challenge this view.

7.2.4 What are the economic costs/benefits of grassland cultivation?

We have no current figures for the UK as a whole, but the Department of Agriculture and Rural Development (DARD) for NI have estimated the costs of establishing grass conventionally at £357 ha^{-1}. As stated earlier, this is written off over 7 years for a silage sward and 15 years for a grazed sward. The cost of producing grass for grazing is taken to be £32 t^{-1} DM cash cost and £73 t^{-1} DM full economic cost. Corresponding costs for 3-cut silage are £51 for cash costs and £85 for full economic costs. So assuming 8 t DM ha^{-1} produced per annum in either system, and taking account of the expected lifetime of the sward in each system, sowing and establishment costs account for 4% of the costs per annum for grazing and 7.5% of the costs in the silage system. Regarding the benefits to be accrued from reseeding, while it was considered that a reseeded sward could produce 20-30% more animal output than permanent pasture, this would seem to be an overestimate of the amount of DM produced. For example in a 10 year liming trial in Co Antrim, Stevens & Laughlin (1996) found a mean advantage of only 9% in production with a reseed compared to a permanent pasture over a range of N fertiliser and lime treatments. However, the higher nutritive value of perennial ryegrass over the secondary grasses found in permanent pasture might contribute a further 10% advantage in animal production. In another series of experiments, conducted between IGER and ADAS from 1983, no systematic differences in yield response of reseeded swards could be identified between regions or soil types. Reseeding resulted in substantial differences in yield in the first year compared with permanent swards when both received 300 kg N ha^{-1}, but in subsequent years, differences were small (Hopkins *et al.*, 1990).

7.3 Research: state of the art

7.3.1 Nutrient losses

Ploughing short-term (1-6 year) leys releases 100-250 kg N ha^{-1}, according to the length of the ley and the soil type (Darby *et al.*, 1988; Johnston *et al.*, 1994). This agrees well with measurements of 150-160 kg N ha^{-1} added to soil by grass and grass-clover leys grown for 6-7 years on a sandy loam soil containing 10% clay, measured by crop analysis before ploughing and soil analysis after (Mattingly, 1974).

The impact on nitrate leaching of methods of ploughing, or otherwise moving from grass to arable crops was tested in some field trials at Coates Farm (Leach *et al.*, 2002). Unploughed ley leached 5 kg N ha^{-1}; winter wheat direct-drilled into the sprayed-off ley leached 35 kg N ha^{-1}; conventionally sown winter wheat (ploughed, cultivated, sown) leached 70 kg N ha^{-1}; conventionally-sown winter wheat given an extra cultivation to improve the seedbed leached 80 kg N ha^{-1} (It should be noted that this experiment was conducted in a very wet winter). The grass was not ploughed and the crop was not sown until January; 3 months later than usual. Hence, the relatively small losses compared to the 100-250 kg ha^{-1} given above. Thus, the impacts of ploughing out grass on the environment can be alleviated by good management practice. Ploughing permanent grassland can release up to 4 t N ha^{-1} over 20 years, with losses of up to 500 kg N ha^{-1} in the early years (Whitmore *et al.*, 1992). Lloyd (1992) compared nitrate leaching from leys of differing N status (i.e. different management histories) after ploughing and returning to cereal cropping. Over three following winters, total losses were *ca* 120, 250 and 1000 kg NO_3-N ha^{-1} for swards of low N status, moderate N status or with a history of excessive N applications and slurry dressings, respectively. Leaching losses were sometimes greater in the second winter after return to cultivation.

Spring, rather than autumn, cultivation is suggested as a means of decreasing nitrate leaching. It is argued that the newly planted spring crop can use any mineralised N before the onset of drainage next winter. However, much depends on the synchrony between N release and N uptake by a following crop; if substantial N mineralisation occurs after senescence of the following cereal crop, mineral N will accumulate post-harvest and be susceptible to subsequent leaching. Most work has considered nitrate leaching after conversion of grassland back to arable. Leaching losses may be less following cultivation and reseeding, particularly in the second winter when the established grass sward can utilise much of the mineralised N. Timing of reseeding is also important. Autumn reseeding leached between 60 and 350 kg N ha^{-1}, depending on soil type and sward history, but leaching losses in the second winter after cultivation were the same as undisturbed pasture and spring reseeding had little effect on the next winter's leaching (Shepherd *et al.*, 2001).

Recent and unpublished work at IGER has determined that losses of P can be classified under 'short' and long' term effects. In the short term (i.e. weeks) following reseed, the predominant effect is on the physical detachment and consequent removal of P associated with soil particles and colloids. In one study, a spring sown sward (early May) received 94 mm rain over 16 days (57 mm occurring in a 24h period). The result was accelerated losses of P that were equal to 3.75 kg total P ha^{-1} and exceeded the total annual export previously determined under permanent pasture. The long term effects on P transfer (i.e. over a period of months) are on the leaching of soluble P. There is evidence that tilled grassland results in a short and long term increase in soluble P in the soil profile, presumably related to increases in mineralisation through altered patterns of wetting/drying and increased soil aeration (Turner & Haygarth, 2001). This effect has been shown to remain for a number of weeks, but is reduced to the pre-tillage state when around 50% of sward cover is achieved. Other IGER hill-slope studies have shown that in undrained grassland following tillage and reseed, solubilisation of P is only marginally higher in both concentration and estimated load than undisturbed grassland (0.8 *vs* 0.76 kg total P ha^{-1} y^{-1}). Conversely, after tillage of drained grassland, the load was lower after reseed than under permanent pasture (0.34 *vs* 0.89 kg total P ha^{-1} y^{-1}).

In a study of leaching losses from organic farms in England and Wales, Stopes *et al.* (2002) measured nitrate losses of 45 kg ha^{-1} N during the organic ley phase (including the winter of ploughing out) and Cobb *et al.* (1999) measured leaching losses of between 119 and 132 kg N ha^{-1} following autumn ploughing of leys. Spring incorporation prior to spring cropping, where possible, has been shown to minimise leaching loss (Watson *et al.,* 1993). Other factors such as grazing intensity and sward composition have also been shown to be important in determining the quantity and pattern of N release following ley incorporation (Davies *et al.* 2001). There is little information available on gaseous losses from organic farming systems. In the only known UK study, differences in methane and N_2O emissions from ley and arable phases of the rotation were found to be less marked than in conventional systems (Ball *et al.,* 2002).

7.3.2 Soil quality

Sowing leys increases soil organic matter content (SOM). On a sandy loam soil with 10% clay that had been in arable production for >100 years, short-term grass and grass-clover leys of up to 7 years increased organic carbon (OC) contents of soils from the very low base of 0.7-1.0% by amounts up to 0.2% (Johnston *et al.*, 1994).

The two ley-arable experiments at Rothamsted Experimental Station study the build up and depletion of SOM in great detail. They were started in 1949 on soils of contrasting histories: one field had been in arable crops for many years and the other in permanent grassland. They measure the effects of various 3-year leys on the yields of three subsequent arable 'test' crops, i.e. a 6-year cycle. The yields of the test crops are compared with those in all arable rotations. In addition, some of the plots in permanent grassland were retained on the grassland site, and some of the old arable plots were sown to grass and have remained in grass since.

Carbon contents of the soils are shown in Figure 2. The main finding was that soils that had supported arable crops over a long period and remained in arable, maintained constant OC contents, whereas soils that were ploughed out from grassland and put into continuous arable crops steadily lost OC. Soils in permanent grass continued to gain OC; soils sown to grass from arable gained OC slowly, and continued to do so after 30 years. The effects of the 3-year leys were small. Under grass and grass-clover, OC was only 0.2-0.25% larger than the continuous arable soil; lucerne did not increase OC.

Ploughing up arable land reduces SOM, the rate again depending on soil type and management. The effect of management on SOM in soil ploughed out from grass is shown in Figure 2, and also in Figure 3. Permanent fallowing causes the greatest loss of carbon: 50% in 20 years. However 40% of the original carbon content was lost in 20 years when two root crops and one cereal crop were grown in rotation, and 30% in 30 years under a 6-course rotation of three cereals, two root crops, and a 1-year under-sown grass ley.

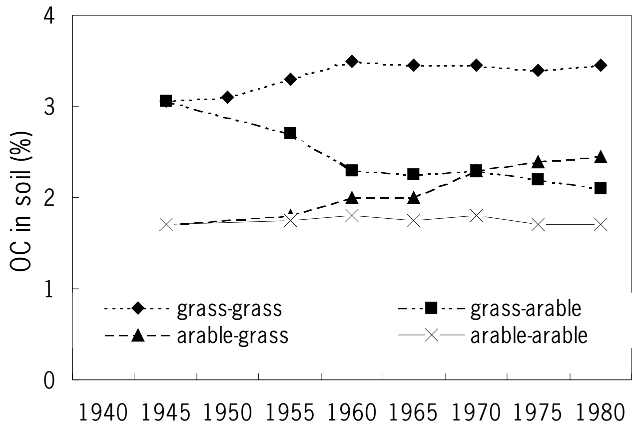

Figure 2. *Effect of ploughing out grass and sowing grass on soil carbon content. Data from the Rothamsted Ley-arable experiments (Johnston, 1986).*

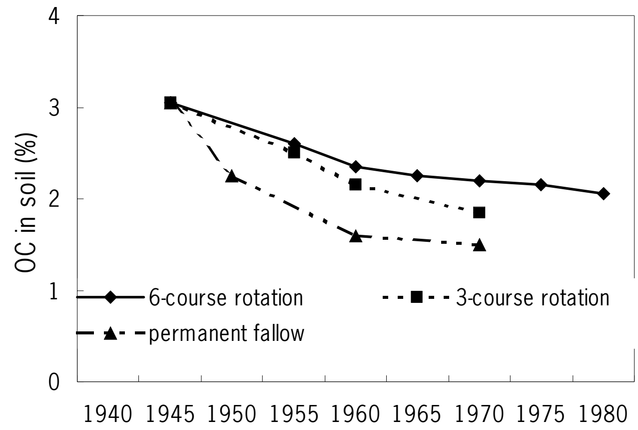

Figure 3. *Effect of three farm systems (rotations) on soil carbon content (from Johnston, 1986)*

There is much concern over the impact of agriculture and land management generally on soil biodiversity. Clearly cultivation is a major disturbance to soil and ploughing up grassland for reseeding or conversion to arable would be expected to have a significant impact on soil biological properties. It is well known that cultivation reduces the number of earthworms in soil. Recent attempts have tried to study to impact of soil management, including cultivation, on the microbial community in soils.

The BIOLOG technique (Garland & Mills, 1991) studies the functional diversity of soil microorganisms by adding various carbon substrates to a soil extract. It is restricted in its application because only a small fraction of soil organisms (a) can be extracted, and (b) will grow in culture. Despite this it has had some success. Substrate Induced Respiration (SIR) seeks to overcome some of the problems of BIOLOG by adding substrate to soil and measuring respiration, often as CO_2 production.

Figure 4 shows a Principle Component Analysis of some SIR and BIOLOG profiles from grassland and arable soils ploughed and sown to arable crops. Both show that, before cultivation, there were large differences in the functional diversity of grassland and arable soils and significant differences between the two ley plots. After cultivation, the microbial populations appear to show a reduction in functional diversity. However, it must be said that cultivation has been a part of most agricultural systems for thousands of years. Microbial communities will have evolved strategies to cope with soil disturbance. The microorganisms in the 'ley' plots had been in arable earlier in the cycle. Communities obviously re-establish under grassland quite quickly.

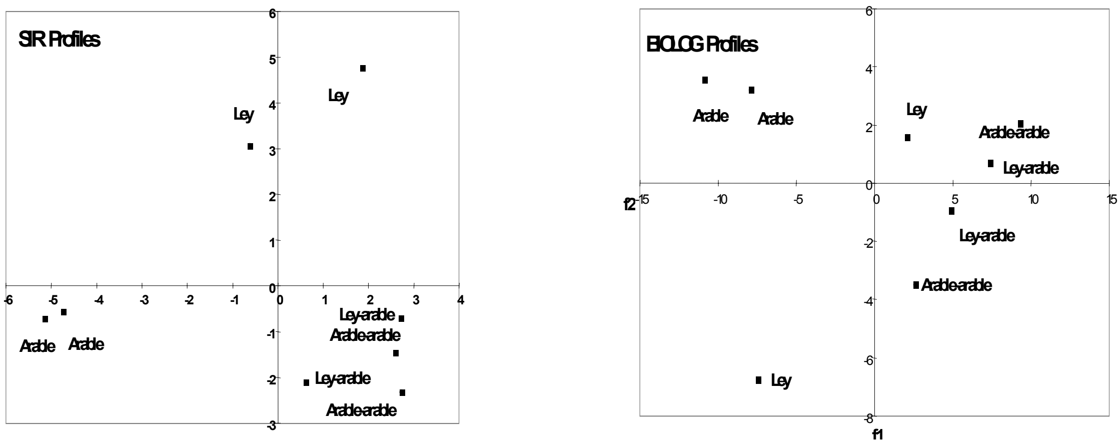

Figure 4. *Principal Component Analyses of Substrate Induced Respiration and BIOLOG data from grassland soils ploughed and put into an arable rotation.*

The impacts of land management practices have also been extensively studied using isotopic pool dilution to measure gross nitrogen cycling processes (Stockdale *et al.*, 2002). A large ratio (> 1) of gross nitrification : gross immobilisation suggests an oversupply of nitrogen to a system. Combined with measures of nitrate and ammonium pool sizes and residence times these can indicate nitrogen saturation, ecosystem stress and an increased risk of nitrogen loss to the environment. Figure 5 shows some data for arable, grass and woodland ecosystems. The reseeded grassland is clearly oversupplied with nitrogen and prone to loss while the unfertilised permanent grass is a stable, N-tight ecosystem.

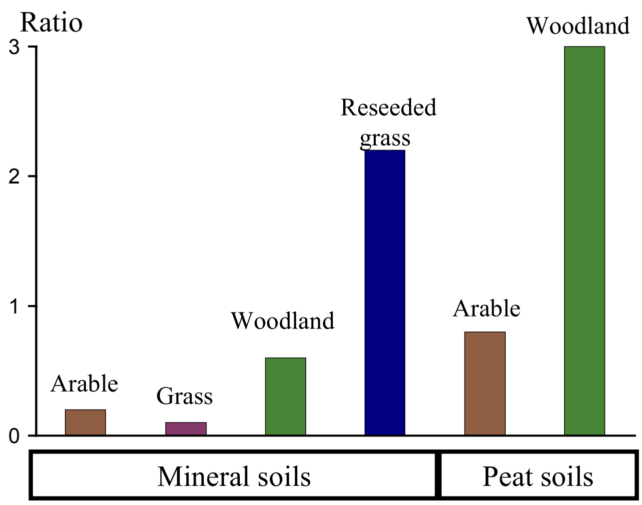

Figure 5. *Indicators of nitrogen saturation (gross nitrification / gross immobilisation) of some ecosystems.*

7.3.3 Crop/animal performance

Nitrogen released from ploughing out leys is, of course, of benefit to subsequent crops. However, the early results from the Rothamsted ley-arable experiments showed that this benefit could be replaced by N fertiliser. The extra organic matter in the treatments ploughed from grass did not increase yields of most arable crops, only potatoes. Later on in the experiment the extra SOM did benefit yields of root crops and spring barley. There were also indications of the benefits to water holding capacity of extra SOM, and that less N was needed for optimum yields in soils containing more SOM. We hypothesise that new, high-yielding varieties that place a greater demand on soils for water and nutrients would benefit more from extra SOM.

A recent nine year study in NI, however, demonstrated increased yield and profitability of crops in an arable-ley rotation with a two year grass break verses an arable rotation, the increase being greatest where fertiliser and agro-chemical use was restricted (Easson, 2002). The presence of the ley in the rotation was associated with reduced weed and disease pressure in the succeeding three crops as well as increased mineralisation of carbon and N.

Current fertiliser recommendations (MAFF, 2000) make allowance for the N released from ploughing leys. The allowance depends on an assessment of the N status of the ploughed ley, based on the length of the ley but also the intensity with which the ley has been fertilised, cut or grazed. For example, leys up to 5 years old, grown on light sands or shallow soils over sandstone and given small amounts of N or one or more cuts for silage are regarded as releasing minimal additional N (and therefore of having not increased SOM). For illustrative purposes, Table 3 shows the amounts of fertiliser N that can be deducted from the normal requirement of a cereal crop for soils of medium texture and for a deep silty loam.

Table 3. Examples of recommended reductions in the amount of N fertiliser applied to winter wheat, following ploughing out of grass leys of different fertility levels (MAFF, 2000). These are the allowances (kg N ha^{-1}) compared with growing wheat after a previous wheat crop.

Soil type	Previous grass history and N use (kg ha^{-1})	N allowance		
		Year 1	Year 2	Year 3
Medium texture	1-2 yr leys, <250 N annually	0	0	0
	1-2 yr leys, >250 N annually	40	40	0
	3-5 yr leys, >250 N, grazed	70	70	40
Deep silty soils	1-2 yr leys, <250 N annually	0	0	0
	1-2 yr leys, >250 N annually	60	30	0
	3-5 yr leys, >250 N, grazed	100	60	30

There are few data directly comparing the benefits of reseeding on animal production, but apart from the year after ploughing, similar rates of individual animal production were obtained when cattle grazed permanent and reseeded swards at similar pressures (Tyson *et al.*, 1992). For swards receiving 100-200 kg N ha^{-1}, increases in production can generally be achieved more economically from increasing fertiliser use than from reseeding.

Newly sown swards are more vulnerable to pests and diseases than established grassland. Italian and hybrid ryegrasses are more susceptible than other perennial grass species and particularly to attack by Frit fly, which is more likely to occur with sowings in mid-August.

7.3.4 Farm management and economics

One of the main disincentives to the inclusion of leys on land registered for arable production is that subsidies can be obtained for maize, but not grass in arable rotations. This has undoubtedly lead to a reduction in the areas sown to short-term grass leys.

Conclusions

The main impacts of sowing or ploughing grass and grass-clover pastures are on the release of N and P to the environment and subsequent crops. Phosphorus exports are greatest in the short term due to physical detachment of soil particles when the soil is bare. The needs of most crops can be met by fertiliser N in the short-term, but in the long-term the extra SOM from leys may benefit high-yielding new crop varieties. In the same way, the long-term depletion of SOM is important, reducing yields and probably affecting soil structure, water holding capacity and quality generally.

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Part II. Discussions

8. Session I. Nitrogen and phosphorus cycling

D. Hatch & G.L. Velthof

Participants in the discussion: Imelda Casey, Christine Watson, Michael Wachendorf, Phil Haygarth, Jørgen Eriksen, Frank Nevens, David Hatch (Chairman), Gerard Velthof (Rapporteur)

All participants in the workshop have indicated major gaps in our knowledge of the effects of grassland cultivation on N and P cycling and losses. Several topics were discussed in the discussion group. The aims were to assess whether there are results and data to answer the questions and, if not, whether it is important to obtain new data.

Mineralisation and prediction of N supply

- There is a large amount of N mineralisation data from various individual experiments conducted in different countries, but these data have not been combined and assessed.
- Some chemical extraction methods, such as hot KCl extraction, and labile organic components, such as dissolved organic N, are promising indicators for predicting N supply.
- Models can be used to predict N supply, but the models should be validated with experimental results.
- In the Netherlands, the advice is to apply N fertiliser in the seedbed (30 kg N per ha) to stimulate rapid growth of the new sward. It was questioned whether this N application is needed in view of the release of relatively large amounts of mineral N from ploughing in the previous sward.
- Research shows that very low, or even no N fertiliser should be applied when maize, fodder beet or arable crops are grown in the first year after grassland; the target yields can be achieved with low N applications. The amount of N fertiliser should be increased in the second year after cultivation and in subsequent years in view of the decreasing N supply in the arable soil following grassland cultivation.

Effects on phosphorus

- A study in the UK shows that the mobility of P strongly increases after grassland cultivation, but this is only a short-term effect. This increased P mobility may increase the risk of P leaching and increase P availability, but insufficient data are available.
- In wet hilly fields, physical transport of P from the soil surface to ditches or lower parts of the field may be an important pathway of P loss just after grassland cultivation. Soil physical and hydrological conditions are important factors controlling these types of losses.
- There is a lack of information on the effects of tillage on inorganic and organic P in soils.
- There are indications that P deficiency may occur in crops following grassland cultivation in organic and extensive systems. Additional P in the seedbed will be needed for these systems.

Effects of tillage on N and P cycling/losses

- More agronomic data than environmental data are available on the effects of tillage.
- Effects of shallow and deep cultivation on N and P losses are not clear and no recommendations can be made.

- Ploughing of drained, clayey soils may destroy some pathways for preferential flow and, in some circumstances, help to limit N and P leaching.
- In hilly areas, contour ploughing may decrease erosion and losses of N, P and organic matter via physical transport.
- Some possible alternatives:
  - Overseeding
  - Permanent understorey (bi-cropping)
  - Strip cropping (strips of grassland and arable land in one field)
  - Buffer strips: no ploughing near rivers and ditches

Environmentally sound systems for grass-arable crop rotations

- Crops with a high N uptake capacity should be grown after cultivation of grassland, such as fodder beet. Crops with a lower N uptake capacity, such as maize, should be followed by a catch crop (which can be grown as an understorey).
- The high net N mineralisation of cultivated grassland may adversely affect the development of following crops, such as the quality of sugar beet, in terms of sugar content and increased incidence of cereal lodging if soil N supply is not allowed for in fertiliser application rates.
- When catch crops are grown, e.g. undersowing in maize or cereals, a strategy should be devised to ensure that the release of N when the catch crop is cultivated is attuned to the N uptake period of the following crop. Otherwise, the N in the catch crop may be lost.
- In agricultural systems, including organic systems, the choice of the crop following grassland is based on the economic value and does not usually include an assessment of the risks of N loss.
- Decreasing the age of grassland in ley-arable systems to less than 3 years is too expensive.
- A study in the UK suggests that N losses are not predictable in the early period of grassland (1-5 years) and there is no evidence that the risk of N loss increases with ageing during this period.

Leaching of dissolved organic N

- A study in the UK shows that the amount of dissolved organic N in the soil increases after grassland cultivation. The dissolved organic N may be mineralised in the soil, but may also leach to ground- and surface waters, where it can be mineralised and nitrified. This may be a pathway of nitrate pollution of ground- and surface waters, but there is a lack of data to quantify these losses.

Changes in the ratio between N leaching and denitrification

- Grassland cultivation, grassland ageing and grass–arable rotations all have a large effect on the content and composition of organic C in the soil and may strongly affect the denitrification potential and ratio between N leaching and denitrification. However, there are no studies and data in which the effects on this ratio are quantified.
- Nutrient management of grassland fields should be aimed at decreasing total N losses and not at transferring one pathway of N loss to another, e.g. replacing N leaching by denitrification.
- More integrated studies are needed in which all N and P processes are quantified. Most studies carried out in the past have been focussed on only one aspect, e.g. mineralisation, N leaching , or denitrification and from which it is difficult to obtain an integrated view of the effects of increasing sward age.

N mineralisation in ploughed grass-clover swards and N fertilised swards

- In a study in the UK, N mineralisation from a cultivated grass-clover sward was higher than that of a N fertilised sward. In studies in Denmark and Germany there was little difference in N mineralisation between cultivated grass-clover and N fertilised swards.
- The N concentration in residues of grass-clover swards is higher than that in N fertilised swards, but the total amount of residues of grass-clover swards is smaller than that of N fertilised swards. Overall, the total amount of N is similar in residues from both swards.
- It was suggested that the effects of management (cutting/grazing, animal manure, N rate) on N mineralisation are larger than the difference between clover-grassland and N fertilised grasslands.

Importance of using whole systems when quantifying N losses

- Analyses of whole agricultural systems are important. Not only should nutrient cycling be included, but also animal performance, crop quality, use of pesticides, water management, and socio-economic factors.
- Whole-system analyses are very challenging and important, but difficult to fund.
- In the Netherlands, there is a strong focus on whole-system analyses. The dairy farm 'De Marke' is an example of integrated research on whole farming systems, but there are also other projects in which whole farming systems are studied.
- Besides studies of real farms, desk studies can be carried out in which systems are created using data and information from separate studies.
- The farmer is an important part of the agricultural system and the knowledge and behaviour of the farmer is often implicit and difficult to quantify or incorporate into models.
- The EU Water Directive is based on catchment scale. Thus, whole-system analyses should not only focus on the farm scale, but also on the regional and national scale.

Effect of soil microbiology/biodiversity on nutrient cycling

- The effect on microbiology/biodiversity is less important for intensively managed agricultural systems, with a high input via mineral fertilisers (these systems are already strongly 'disturbed'). For extensively managed grassland and rangelands this aspect is more important.
- A study in the UK showed that the total amount of microbial biomass strongly decreased after cultivation and that it might take several years before the initial amount was regained. Microbial activity, however, rapidly recovered (within several months) suggesting that only part of the microbial population in the soil is active in nutrient cycling.
- Let nature build up fertility? There are no data on effects of grassland use on microbial populations. In the Netherlands, there is an archive with dry soil samples (from the year 1879) which could be used to assess changes in biodiversity with time by analysis of DNA profiles. However, it is not known what the effects on DNA are of storage of these dry samples for a long time.

Conclusions

There are many gaps in our current knowledge and further research is required to give more quantitative information about the effects of grassland cultivation on N and P cycling. However, there is already a good understanding of many aspects and much data has not yet been published and there are other sources of data in the 'grey' literature. Before new research is started, it is recommended that an overview of the existing data sets is obtained and that these data should be combined and analysed to assess their relevance. On the basis of this overview, conceptual models on nutrient cycling can be developed and the main gaps in our knowledge identified: proposals for further research can be then be made. However, this type work is time-consuming, because there are many studies and the data are distributed between many research groups throughout Europe. Additional funding by e.g. EU (COST action) could facilitate the exchange of data and knowledge between these research groups. A first step towards closer collaboration and exchange of information will be to establish a permanent working group on grassland renovation for the European Grassland Federation.

9. Session II. Soil quality and water balance

F. Vertès & D.W. Bussink

Participants in the discussion: Friedhelm Taube, Keith Goulding, Sjaak Conijn, Mark Shepherd, Françoise Vertès (Chairman), Wim Bussink (Rapporteur)

Questions that were discussed:
1) How should we measure soil quality and especially the impacts of grassland resowing and grass-arable relations on soil quality? Points of interest are:
    - What is soil quality and have we a common definition?
    - Can we measure soil quality and how?

A list of criteria was proposed (cf. NL report) as basis for discussion:
- nutrient supply (redistribution of nutrients)
- water supply
- soil aggregate stability
- slaking susceptibility
- poaching susceptibility
- bearing capacity
- compaction
- erosion
- rooting depth/capacity
- air content
- levelling
- biodiversity
- microbial activity

2) What are the effects of renovation on C-fixation capacity? Is there an optimum tillage depth? Is changing grassland into arable land a time bomb?

3) What are the effects of farmers' management skills on soil quality?

4) What is the effect of grassland age on C- and N-mineralisation after destruction?

Discussion

Question 1: How should we measure soil quality and especially the impacts of grassland resowing and grass-arable relations on soil quality?

The discussion started in mentioning that the demands of society regarding soil quality are variable and sometimes conflicting. For example, cheap food production with a good quality conflicts with the demand for a high bio-diversity (i.e. grassland with flowers). Research of maximum nutrient and water use efficiency could lead to arable-ley production systems instead of permanent grassland and maize monoculture practices.

It was agreed that soil type, climate and topography have a dominant effect on soil quality. These factors cannot be changed and determine to a large extent if there should be permanent grassland, arable land or ley-farming.

It became clear that there is a difference in judgement of soil quality parameters. In some countries the agronomic arguments prevail, which make it possible to grow potatoes on peat soils that were originally grassland. In other countries it is not allowed to plough peat bogs, because environmental arguments prevail. Understanding of the different argumentation between countries is necessary to continue in this field. It was also argued that we should focus more on a holistic approach, including social and natural factors. This also requires a farm scale approach.

Many of the parameters mentioned in question one are known and can be quantified. These factors may, however, not be the reason why there is permanent grassland, ley farming or arable farming on certain soil types. Farm size and subsidies may have a large effect on land use. Economics often overrule soil quality aspects.

The effects of soil compaction are less well understood. The group mentioned that there is little research available on this issue. The same holds for water supply. It is known how much water a soil can deliver. Grassland renovation, which causes a redistribution of organic matter through the soil profile (0-20 or 30 cm), increases water-holding capacity. This is known qualitatively but not quantitatively. This becomes more important in case of restrictions on water use. It should then not only be studied on a field scale but also in a whole-farm approach.

Although we know a lot about nutrient supply it became clear that in many countries factors as soil pH are far below the optimum. This needs more attention. In general, nutrient supply by the soil itself and the effect of renovation on nutrient supply becomes more important as nutrient input levels have to decrease.

There is also a lack of knowledge about the optimum biodiversity in soils.

Question 2: What are the effects of renovation on C-fixation capacity? Is there an optimum tillage depth? Is changing grassland into arable land a time bomb? Answering question 2 has been combined with question 4: what is the effect of grassland age on C- and N-mineralisation after destruction?

It was felt that there is a lack of knowledge regarding C-sequestration and its effects on C- and N-mineralisation. Knowledge gives better insight into best soil management (permanent grassland, ley-farming or arable grassland but also into the desired frequency of renovation and resowing). The other questions were not discussed.

Question 3: What are the effects of farmers' management skills on soil quality?

It was mentioned that more knowledge transfer is needed about soil parameters to make good decisions about the farming system. Even if the outcome may be overruled by economics, it was important to give elements to farmers that help to take their decision knowing the consequences of their choices. Thus to answer to the question: what will happen if I do this ?
The other important question is: what are the objectives? and how to manage them? This refers to the first question and in some cases to the equilibrium between farmers and society / nature protection needs.

Finally, the key factors that must be considered to make choices between different cropping systems and the points that need further study are presented in the scheme below. We think that we should focus research on parameters as C-storage, soil compaction, biodiversity, water supply and soil structure for each of the following cropping systems: permanent grassland, grass-arable farming and arable crops. Differences in climate and soil type have a large impact on these parameters. This may result in different recommendations for countries/regions regarding the choice of the optimal cropping system. Moreover, society and farmers may have different objectives and regulations - as pointed out before - with respect to land use (i.e. farm economics versus nature conservation). It makes clear that a multidisciplinary approach becomes a necessity in addressing these issues.

The empty fields in the scheme should be filled with our present knowledge and at the same time with research needs if our present knowledge is inadequate. For each climate-soil combination you might have a different result. We have not completed the scheme, because some fields could be filled with results of questions debated in the three others sessions (nitrogen and phosphorus cycling, crop/animal performance and farm management and economics) and because there was not enough time during the discussion.

Parameter	Permanent grassland	Grass-arable farming	Arable crops
C storage and release			
Soil Compaction			
Soil fertility (nutrients, pH)			
Biodiversity (plants, fauna, micro-organisms			
Water supply, soil structure			

10. Session III. Crop and animal performance

K. Søegaard & H.F.M. Aarts

Participants in the discussion: Karen Søegaard (Chairman), Frans Aarts (Rapporteur), Hagen Trott, Lindsay Easson, Alex de Vliegher, Anne Marie van Dam

Performance is based on herbage production, herbage quality and intake by cattle. Grassland will be re-established if performance is too low, in the opinion of the farmer. A problem is that he has no practical standards to decide whether performance is acceptable or not. So farmers rely on their personal feelings. Gross crop production seems to be less important in that decision. Quality, measured by 'a look on animal behaviour during grazing' seems to be most important, especially during periods with relatively low grass quantity or quality, like in dry periods in summer and wet periods in autumn. An important argument also seems to be the clover content of the sward and the distribution of that clover over the field. The visual aspect might also be important; farmers do not like to see tall weeds in their grassland.

Maintaining high performance depends on soil type and climate conditions, and is highly influenced by management (grazing and cutting, fertilisation). Cutting seems to be more destructive to sod quality than grazing. It is not clear what the impact is of improved grass and clover varieties on persistence of crop performance.

In discussions regarding re-establishing grassland it is important that a distinction is made between permanent grassland and temporary grassland, as part of a grass-arable rotation system.
Some countries rely almost fully on temporary grassland (Denmark), others on permanent grassland (Ireland). Some countries rely on both systems, depending on soil type (Belgium and the Netherlands). Temporary grassland is preferred if good performance of permanent grassland is difficult to maintain, like on dry sandy soils (damage to the sod by drought during summer or by frost during winter). Temporary grassland seems also to be preferred if clover is more appreciated.

The main questions that should be solved during the next two years are:

- what are farmer's motives for permanent grassland versus temporary grassland?
- how can performance be quantified in a way that can be used by a farmer in making decisions?
- what are the motives for re-establishing permanent grassland and for the length of the grass period in a grass-arable system?
- how can high performance be maintained after re-establishing grassland?

11. Session IV. Farm management and economics

J. Humphreys & I.E. Hoving

Participants in the discussion: James Humphreys (Chairman), Ib Sillebak Kristensen, Ignace Verbruggen, René Schils, Idse Hoving (Rapporteur)

Points of discussion:
1) Direct costs of resowing
2) Cost/Benefit of resowing
3) Legislation

Re 1: Direct costs of resowing

To compare costs between countries an overview has been made as shown in Table 1. Only the main costs are presented.

Table 1. Main costs of resowing permanent grassland.

	Belgium	Ireland	The Netherlands
Soil analysis			57
Chemical destruction + spraying	55	60	56
Lime + spreading		83	
Rotary tilling	56		68
Ploughing	63	56	73
Levelling		16	
Seedbed preparation	50	48	41
Sowing	41	25	54
Seed	100	95	127
Herbicides + spraying		32	63
Fertiliser + spreading		77	84
Rolling		20	
Total costs	365	512	623

Denmark is not mentioned in Table 1 because there is predominantly crop rotation, and almost no permanent grassland. The differences in costs of resowing between countries depend primarily on the inputs included (Table 1); for example the inclusion of soil analysis by the Netherlands. It could be argued that soil analysis and the application of lime and fertiliser are an integral part of nutrient management and maintenance of soil fertility on the farm and perhaps should not be attributed directly to the costs of resowing. On the other hand, soil analysis during resowing is highly recommended because of turning down the sward. The nutrient status of the deeper layers is unknown. Otherwise, when comparing the costs of individual operations across countries, the differences are not striking. It is possible that Dutch farmers, in particular, use more seed than is strictly necessary. There is a need for examination of the possibilities of reduced tillage operations or the adoption of new technologies that might contribute to the reduction of resowing costs.

Re 2: Cost/benefit of resowing

The advantages and disadvantages associated with three main general scenarios that need to be assessed:

- Permanent grass
- Regular grass to grass resowing (*i.e.* every five years)
- Grass and maize rotation

The relative costs and benefits associated with each of the above three scenarios depend on factors such as climatic differences etc. within each country that have an impact on the costs of production and also on factors that have an impact on the saleability and value of the product. For example, in Ireland a long grazing season is favoured by a relatively mild wet climate that is not particularly conducive to maize production with existing cultivars. This offers the possibility of relatively low costs of milk production based primarily on grazing virtually permanent grassland. However, maximising dependence on grazed grass involves highly seasonal production and a concomitantly lower milk price. In contrast, the relatively long and harsh winter and summer drought in Denmark and Northern Germany necessitates the provision of substantial quantities of conserved feed. Access to markets offering high prices for year-round supply of milk requires the provision of forage of high nutritive value. Corn and maize silage meets these requirements and hence is an integral component of the system of dairy production commonly practised in these regions. Furthermore, the experience in Denmark is the relatively rapid deterioration of swards over a period of three or four years, especially under cutting management. This rapid deterioration may be due, to a large extent, to the relatively long cold winter and the prevalence of summer drought conditions experienced in Denmark. Therefore, in Denmark and Northern Germany milk production tends to be based on rotation of short-term grass leys (of about three years duration) and corn and maize production.

The situation in Belgium, Germany and the Netherlands is between the Irish grazing system and the Danish system of high nutritive forage. In the grazing season grass is supplemented with maize silage. In general, grassland is not rotated with maize or other crops. Depending on soil type and intensity of use, the sward deteriorates more or less rapidly. Crop rotation is only common practice in organic farming in order to try to retain soil fertility. Maize silage is generally an integral component of dairy production systems because of the high intensity of production and the relatively high nutritive value of maize silage. The production of maize makes better use of soil moisture, more efficient use of fertiliser N on a whole-farm basis and is a practical crop for fields that are at an inconvenient distance from the milking parlour.

In systems of dairy production that are primarily grass-based, i.e. grazed grass and grass silage, the benefit of resowing is dependent on the increased productivity associated with the sown sward exceeding the costs associated with reseeding. The increased productivity is dependent on the survival and longevity of the sown sward. As pointed out above, climate has an important influence on the rate at which a sward declines, *i.e.* the impact of harsh frosty conditions during the winter in Denmark. In the Netherlands and Belgium sward deterioration can occur within four or five years on sandy soils that are prone to drought. Grassland management also influences the rate of deterioration with intensive cutting management tending to increase the rate of decline. Under such circumstances periodic renovation of grassland is necessary.

In order to properly assess the cost/benefit of grass to grass resowing it is necessary to have reliable data on the increased productivity (forage yield and nutritive value) that is directly attributable to resowing in the years following resowing. These issues would have to be assessed under a range of different scenarios relevant to production systems in different regions. Detailed knowledge on the reasons for the deterioration of swards would be an important aspect of this.

Main questions

- Possibilities of shallow tillage?
- Are there alternatives for reseeding operations?
- What is the effect of grassland renovation on DM yield, herbage quality, net uptake and the economic perspective for farmers?

Re 3: Legislation

In general, farmers undertake resowing for economic reasons. However, there are environmental implications associated with resowing of grassland and probably the most important of these is the large increase in mineralisation and release of soil organic matter N. This can contribute to losses of N to the wider environment, especially via losses of nitrate to surface and ground- water. In the Netherlands ploughing of grassland is prohibited between mid-September and the end of January. Generally this legislation does not have a strong impact on general grassland management, although this legislation is opposed by the bulb-growing sector for agronomic reasons. Also in the Netherlands there may be requirements to further reduce N thresholds on dairy farms. This would tend to increase the proportion of land area devoted to maize production on such farms. In Ireland, agriculture is the source of approximately one third of greenhouse gas emissions. It is the source of most methane and nitrous oxide emissions, which are gasses of high global warming potential. Since contributing substantially to emissions and accounting for only 5% of Gross Domestic Product, reduction in both ruminant livestock numbers and fertiliser N use is being both promoted and imposed by a range of measures. This is likely to result in a shift towards more extensive low cost grazed-grass-based systems of production. In Belgium a change in timing of resowing is expected due to changes in the way subsidies are paid. These issues are likely to have an impact on the cost/benefit of the grassland resowing and on grass arable rotations.

Main questions

- What are the economic effects of N losses caused by grassland renovation?
- Which practical support can we give to farmers facing grassland renovation?

12. Plenary discussion

F. Taube, A.M. van Dam & J.G. Conijn

Frequency of resowing

Taube: With conversion from grazed to cut grassland resowing is needed more often. In a permanent cutting system resowing is needed every 5-7 years. Swards deteriorate faster with cutting 4 times than with cutting 6 times a year.

De Vliegher: Heavy cuts have a negative effect on sward quality.

Søegaard: Sward quality and clover content can be maintained longer by alternating grazing and cutting.

Animal performance

Taube: Animal performance did not get much attention yet, we have been focussing mainly on the plant production part. However, it is important for the economic evaluation. It depends on the voluntary intake and on the digestibility of the sward. The nutritional value of the grass should be described in more detail.

Schils: Farmers experience that young swards have a higher nutritional value.

Bussink: Also, young swards are grazed more easily (higher intake, lower grazing rest), so that effectively, net yield may be higher than for old swards. It is difficult to measure this.

Farming system

Humphreys: Farm size determines choices: when a farm is bigger, with more cows, possibilities for mechanisation will be different, which influences management choices, e.g. more fodder crops mechanically harvested instead of grazing. The economic value of pastures then decreases.

Taube: What is the labour demand of different systems during the year?

Humphreys: When there is little labour available, there is a large potential for reduction of labour cost. This will result in a more extensive farming system.

Haygarth: There has been little research at farming systems level. It is now a challenge to integrate detailed research performed at different scales by modelling or experiments.

Shepherd: We will need modelling, because experiments at the farming systems level are too complicated.

Taube: We need on farm research. At the time this was started because of lack of money, but it has proved to be very effective. Furthermore, data obtained from controlled experimental fields may not be adequate for extrapolation to farmers' practice.

Aarts: We have to look forward: what will be the dairy farming systems in 20 years, and what are the research needs now for achieving these systems in 2022?

Environmental impact of resowing

Trott: Are there alternatives for ploughing and resowing which have a lower impact on the environment?

Schils: Overseeding is sometimes used as an alternative. It is cheap, but not always successful and therefore farmers are not very enthusiastic about it.

Haygarth: Now there is much emphasis on N losses. There is very little known about P losses.

Part III. Conclusion

13. Synthesis, conclusions and follow-up

F. Taube, A.M. van Dam & J.G. Conijn

13.1 Some gaps in knowledge detected during the workshop

1. Differences between countries are related to climatic and soil factors. These should be studied in more detail, for a more systematic approach and for better understanding of the situation in NW-Europe.
2. C and N fluxes after tillage of swards are not well understood. What is the effect of grassland management before and after tillage?
3. Soil compaction in grazing and cutting systems is a relevant aspect of soil quality, because it may influence yield. Development of compaction with time as a function of management should be studied.
4. Biodiversity is another aspect of soil quality. It has not yet been evaluated for different farming systems.
5. Water balances and water use efficiencies of various systems are not known.
6. The nitrogen fluxes at whole-farm scale should be known in order to evaluate differences in land use systems, such as grazed or cut grassland, permanent grassland vs. ley-arable farming, etc.
7. Statistical data of the countries are very weak. We should get more reliable data about farmers' practice, like frequency of reseeding, etc.
8. We know too little about the criteria/motives that are relevant for farmers for decisions on grassland renewal.
9. We have an understanding of what happens in our experimental fields, but too little is known about the processes in the real farm situation.
10. The use of simple models, which can be easily applied at a real farm, should be stimulated rather than the complex mechanistic models. To improve the validity of these models, they should be evaluated with data from various countries.

13.2 Ongoing research in the participating countries

1. The Netherlands

A project on grassland renovation and ley–arable rotations runs from 2001 to 2005. Focus is on N cycling and pathways of N losses. There are field studies, and a decision support tool for farmers is being developed with a cost-benefit analysis. The project is linked to monitoring studies on farms.

2. Belgium

- A long-term experiment on ley-arable rotation is continued, together with the Netherlands. In this experiment permanent grassland, permanent arable farming and the ley-arable rotation are compared with respect to yield, N fluxes, etc.
- A resowing experiment is going on with resowing a part of a sward every year. This will go on for 2 more years.
- An experiment with spring cultivation of grassland followed by maize will go on for 1 more year.

3. Denmark

- An experiment is continued on studying N fertilisation of grassland and the losses by leaching and denitrification as function of grassland age and cultivation.
- A new program is planned (but funding is not yet sure) on N effects of grassland cultivation, the N balance of ley-arable rotations and management of clover in swards.
- A farming system model is developed including soil N processes, management of clover in swards and grazing/cutting ratios. The working of the model will be checked at pilot farms.
- Research on pilot farms is done to improve grass-clover management.

4. France

- The seasonal effect of sward destruction is evaluated.
- A project is being initiated on measurements and modelling gross C and N fluxes under grass swards and after destruction. Methods and models developed by S. Recous and B. Mary are used, including ^{15}N and ^{13}C techniques.
- A long-term field experiment with C sequestration and climate change is performed with various farming systems (permanent grassland, grass/clover swards).
- A new federative project on grasslands, co-ordinated by G. Lemaire: Role of grassland in sustainable agricultural land use. Medium and long term impact on biogeochemical cycles and biodiversity, at field and territory levels.

5. Germany

- A trial has been performed on a sandy soil studying crop rotation, permanent grassland and permanent arable farming with respect to yield, quality, N leaching, N fixation by clover, N efficiency of slurry and mineral fertilisers.
- A comparable trial is still running on a loamy soil.
- There is farming systems research studying the effect of different legumes on N supply to the following crop; N fluxes in the organic crop rotation system; quality of organic C and C/N ratio in the soil. This will go on for 2-3 years.
- A whole-farm model from the USA is expanded in collaboration with a modelling group from USDA/USA.

6. Ireland

Current pertinent research topics include:
- Examining the suitability perennial ryegrass cultivars under grazing management.
- N-use efficiency on dairy farms and factors affecting nitrate leaching losses from an intensively managed dairy farm in a vulnerable area.
- Maize as a crop for intensive winter milk production.

Future (in the process of being initiated) research topics include:
- Low-cost non-destructive methods of introducing white clover into extensively managed grassland.
- The impact of the intensity of grassland management on biodiversity.
- Deep pouching as a means of reducing P loss from permanent grassland in areas historically receiving high annual P inputs (i.e. in the vicinity of pig production units).

7. United Kingdom

- There is an 18 month project to develop a soil N supply calculator, estimating N release in soils in different farming systems (grassland, arable farming, horticulture).
- Improved guidelines are being developed for organic farming: use of legume crops and resulting N release (3 years). There is a study on mixed farming with reduced N budgets involving a 5 year project looking at the conversion from a dairy farm to arable farming, with particular focus on N fluxes after ploughing grassland.
- N transformation in the subsoil is studied in England (together with Northern Ireland): denitrification, N_2O emission and leaching.
- A project is running on P losses from land to water. Many data have been collected and will be integrated now.
- Experimental organic farms with different percentages of ley in the rotation are studied with respect to N and P budgets (Scotland).
- A detailed study is done on the transition of ley to arable land.
- Modelling of N flows in rotations is performed on whole farm scale.
- A ley-arable experiment has been performed and will be reported shortly.
- In 2003 a workshop on arable farming systems will be held and the 12th Nitrogen Workshop will be held in Exeter, Devon, UK, organised by IGER

13.3 How to go on after the workshop?

1. In addition to the proceedings (this report) the workshop will also be summarised in a review paper for Grass and Forage Science by Conijn, Taube and Velthof.
2. Continuation of this group within EGF. A working group on grassland renovation will be installed at the EGF meeting in France. We will try to get a session on this subject at the EGF congress of 2004. In France we will present the results of our workshop (combined action of Taube and chairmen of the four themes) at the installation meeting[2]. For preparation of the session at the congress in 2004, a small group will meet at the beginning of 2003 and discuss the progress made sofar. Maybe we have to search for additional (EU) funding.

13.4 Concluding remarks

Watson: We should make contact with the group working on C sequestration in grassland. They have similar interests.

Nevens: Development of a website with experimental data on grassland renovation and ley-arable rotation (something like SOMNET) is an efficient way to make information of various countries available. But this needs extra funding.

Taube: Spreading information about publications in the working group will be a good first start for this.

[2] Some of our plans have been realised at the time of printing these proceedings. We have presented the results of our workshop at the EGF conference in France (May 2002) and a permanent Working Group on ‘Grassland Resowing and Grass-arable Rotations’ has been installed. We agreed with the organising committee of the next general meeting of the EGF to present the progress on this subject in a special session.

Appendix I.
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