PLANT RESEARCH INTERNATIONAL
WAGENINGEN UR

Grassland resowing and grass-arable crop rotations

Consequences for performance and environment

Second workshop of the EGF-Working Group
'Grassland Resowing and Grass-arable Rotations'
Kiel, Germany, 27-28 February 2003

J.G. Conijn & F. Taube (eds)

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J.G. Conijn[1] & F. Taube[2] (eds)

[1] Plant Research International, P.O. Box 16, 6700 AA Wageningen, The Netherlands
[2] Institute for Crop Science and Plant Breeding, University of Kiel, 24098 Kiel, Germany

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European Grassland Federation

EGF is a forum for research workers, advisors, teachers, farmers and policy makers with active interest in all aspects of grasslands in Europe. These aspects include management of all types of grasslands for production, utilization, amenities and conservation purposes.

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Plant Research International B.V.

Address	:	Droevendaalsesteeg 1, Wageningen, The Netherlands
	:	P.O. Box 16, 6700 AA Wageningen, The Netherlands
Tel.	:	+31 317 47 70 00
Fax	:	+31 317 41 80 94
E-mail	:	post.plant@wur.nl
Internet	:	http://www.plant.wur.nl

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General introduction

In Europe, grassland is an important resource for animal husbandry. Productive grass swards and nutritive grass are essential for economical reasons. To maintain these demands grassland should be cultivated if grass sward or soil conditions have deteriorated. Common strategies of cultivation are reseeding of 'permanent' grassland or ley-farming (rotation of grass and arable crops). However, grassland cultivation is more and more subjected to demands of society in terms of reduction of nutrient losses, conservation of biotic diversity, protection against erosion, maintaining carbon storage, etc.

Challenged by these considerations, a group of grassland scientists from seven Northwest European countries gathered in April 2002 in Wageningen, the Netherlands, to discuss the agricultural and environmental issues of grassland resowing and grass-arable crop rotations. Country reports, describing the current situation in each country and the state of the art in research with respect to grassland cultivation, were presented. After these presentations, there were four discussion sessions, focussing on the most relevant processes:

1. Nitrogen and phosphorus cycling
2. Soil quality and water balance
3. Crop development and animal performance
4. Farm managemant and economics

Both the country reports and the outcome of the discussions have been published in Conijn *et al.*, 2002 (see Appendix II for an abstract of this publication). At the end of the Wageningen workshop it was concluded by the participants that the international cooperation and exchange of scientific knowledge should be continued by starting a permanent working group under the umbrella of the European Grassland Federation (EGF).

The Executive Committee of the EGF approved this initiative and officially installed the Working Group **'Grassland Resowing and Grass-arable Rotations'** at the 19th General Meeting of the EGF which was held in La Rochelle, France, in May 2002. In a special session during the General Meeting the results from the workshop in Wageningen were presented by members of the Working Group. The general purpose of the Working Group is to investigate the impact of grassland resowing and grass-arable rotations on the various functions of fodder production systems (such as: productivity, biodiversity, groundwater recharge, water quality, C sequestration, etc.) and to find ways that lead to both economically and environmentally sound farming systems in the future.

The Working Group has continued its cooperation and exchange of knowledge by organising a second workshop on grassland resowing and grass-arable rotations in Kiel (Germany), in February 2003. The main objectives of the Kiel meeting were:

a. to discuss the possibilities for synthesis of Northwest European data and further international collaboration on grassland resowing and grass-arable rotations
b. to make appointments on presentations (subjects, content, (co-)authors) which can be held at the 20th General Meeting of the EGF in Luzern, in June 2004.

Participants of the Kiel workshop (see Appendix I).
Note: G. Springob and N. Forher are not present on this photo.

In order to facilitate the discussions in Kiel, presentations were prepared by Working Group members on either grassland resowing or grass-arable rotations for each of the four above-mentioned sessions in Wageningen. For each session the following aspects were discussed in Kiel:

- key questions (with and without answers) and how they are related to the main problems associated with grassland resowing and grass-arable rotations in Northwest Europe
- (short) state of the art from (un)published data of Northwest Europe
- proposals for further research in this topic

These workshop papers have mainly been based on the proceedings of the Wageningen workshop (Conijn *et al.*, 2002) and most of them can be found in this report.

Theme 1.

Nitrogen and phosphorus cycling

1. Nitrogen and phosphorus cycling in grass-to-grass resowing and grass-arable rotations

D.J. Hatch[1], A. Hopkins[1] & G.L. Velthof[2]

[1] Institute of Grassland and Environmental Research, North Wyke, Okehampton, Devon, EX20 2SB, UK
[2] Alterra, P.O. Box 47, 6700 AA, Wageningen, The Netherlands

1.1 Introduction

Before the widespread use of artificial N fertilizers in both grassland and arable farming, the cultivation of permanent pasture and resowing to grass leys (or intervening arable or root crops) was recognized as a means of releasing and exploiting the accumulated fertility and restoring soil structure. The development of ley farming (Stapledon, 1935), an approach which is also fundamental to many modern-day organic farming systems, was based on the recognition that soil organic matter accumulates over time, and with it soil N accumulates in proportion. This N is effectively immobilized, and in the short term this represents a loss of the key nutrient that drives grassland production. This subject has a long history within grassland research. The first General Meeting of the EGF held in Wageningen in 1965 had nitrogen in grassland as its subject, with papers on soil N and ley farming (Van Burg & Arnold, 1966). More recently, the first report of the EGF working group on grassland resowing and grass-arable rotations reviewed the advantages for carrying out reseeding (Conijn *et al.*, 2002). The timing and other agronomic details associated with cultivation of grasslands has implications not only for the productivity of subsequent grass leys and other crops, but also has both positive and negative environmental impacts. In comparison with nitrogen, phosphorus dynamics in grassland and the effects of tillage on P in soils have received comparatively little attention. In this paper we present an overview of the implications for soil nutrients of cultivating grassland, focussing on nitrogen and phosphorus, and consider the present state of the art and major gaps in the knowledge. The paper is in two parts: section 1.2 deals with grass-to-grass resowing and section 1.3 addresses these issues in the context of grass-to-arable cropping.

1.2 Nitrogen and phosphorus cycling in grass-to-grass resowing

1.2.1 Nitrogen accumulation

Grassland soils typically contain between 5 and 15 t of total N per ha in the top 15 cm (Ryden, 1984), though only a small proportion of this is present as an inorganic form that is potentially available for plant uptake. Under long-term grassland total soil N accumulates as a result of acquisitions from biological N fixation and other atmospheric N sources, fertilizers and other management inputs. Most of the total soil N is organic N and its rate of accumulation under grassland is approximately linear in the early years of a sown grass ley (Tyson *et al.*, 1990). Data from Rothamsted (UK) showed that on loamy soils under long-term grassland it takes >100 years for soil to attain an equilibrium N content, in this case 0.25% w/w of soil (Johnston, 1991). Time required to reach equilibrium might be expected to vary depending on soil texture and other soil characteristics, though comprehensive data are lacking. Tyson *et al.* (1990) recorded an annual accumulation of 15 kg N/ha per year under pasture on a loamy soil over chalk at Hurley (UK), though the annual rates were much greater (75 kg N/ha per year) in the first 10 years. Similar rates of N accumulation were recorded on a long-term pasture on a silty clay loam over clay at North Wyke; of

3000 kg/ha fertilizer applied over 15 years, only 1000 kg N/ha were retained in the soil, this amount being in proportion to C accumulation in a 10:1 ratio (Hatch *et al.*, 2000).
Sward type, management and environmental factors all affect the rate of soil N accumulation following cultivation, and may prevent an equilibrium content being attained. In a 3-year investigation at Hurley on a loamy soil over chalk, increases in soil N were in the range 70-180 kg N/ha per year under grass and grass-clover swards, with the greatest increases being under grazed ryegrass + white clover swards (Clements & Williams, 1967). Intensity of management and sward botanical diversity also affect both the development of soil biota and the utilization of soil nitrate which in turn has implications for the rate of N cycling and its efficiency in terms of sward productivity (Tilman *et al.*, 1996).

1.2.2 Nitrogen mineralization

There is a wide range of reported values of total N mineralization rates, particularly in the first year after ploughing and cultivation of grassland. However, there is no agreed standard method of measurement, though N off-take in herbage harvested from unfertilized plots is widely used as an indicator of soil N supply. In established leys and permanent swards, N mineralization proceeds at rates influenced by agricultural management, e.g. lime applications, changes to drainage status, inputs of manures and other nutrients etc. as well as soil type, soil biota, sward composition, available water capacity and climate. The proportion of total organic N released annually varies from 2%-10%, depending on soil type, e.g. high clay contents protect organic matter from microbial decomposition (Antil *et al.*, 2001). When a grassland sward is cultivated there is incorporation of plant and animal residues, and increased N mineralization occurs due to exposure of organic matter to microbial decomposition and increased aeration. Ploughing short-term leys releases 100-250 kg N ha^{-1}, according to the age of the ley and the soil type (Darby *et al.*, 1988; Johnston *et al.*, 1994). These values agree well with measurements of 150-160 kg N ha^{-1} following grass and grass-clover leys, as measured by crop analysis before ploughing and soil analysis after (Mattingly, 1974). Nitrogen released as a result of cultivation of grassland becomes mineralized and is available for plant uptake by the succeeding resown sward, but a proportion will be lost from the soil N pool through gaseous emissions and leaching. These have consequences for sward performance and the wider environment.

1.2.3 Soil N and sward performance

Data from experiments conducted across a wide range of sites on the fertilizer N response of sown grassland in England and Wales (Hopkins *et al.*, 1990; 1995) have been examined to provide data on herbage production and herbage N content. These include information for nil-fertilizer N treatments which provide not only herbage dry matter yield, but also herbage N content and thereby a measure of soil N supply under defined management and for different site / soil characteristics. Table 1 shows the range of between-site herbage yields and N-uptake rates in nil-N fertilized leys following cultivation of >20-year-old pasture, and Table 2 for leys following previously fertilized long leys. There was no simple relationship between soil organic matter content and N offtake in herbage, and considerable between-site differences exist, which make the prediction of soil-N release difficult.

Table 1. *Annual herbage DM yield and herbage N uptake from newly sown Lolium perenne swards without fertilizer N following cultivation of extensively managed permanent grass in relation to soil characteristics.*

Site	Herbage yield as t DM/ha (3 year mean)	Herbage N uptake as kg N/ha (3 year mean)	% soil total N	% soil organic matter	% clay	Herbage N uptake as % of total soil N
1	2.67	56	0.25	12.3	42	2.19
2	3.28	66	0.40	9.2	21	1.28
3	5.55	126	0.68	12.7	48	1.81
4	5.26	127	0.57	11.1	38	1.75
5	4.57	116	0.35	9.5	25	2.77
6	3.36	74	0.58	16.6	25	1.15
7	2.29	56	0.68	16.8	15	0.89
8	4.00	83	1.06	25.0	25	1.11
9	5.21	122	0.45	10.6	21	2.26
10	4.70	123	0.51	10.8	28	1.93
11	6.56	157	0.42	9.6	22	2.63
12	4.59	110	0.31	6.6	41	2.27
13	4.42	120	0.21	3.8	17	3.26
14	4.65	125	0.49	8.3	33	2.21
15	3.69	122	0.54	11.8	13	1.32
16	5.84	145	0.67	12.6	50	1.53

Investigations of the performance of grass-to-grass resown swards under grazing have, in most cases, used N-fertilized grass swards or sown grass-legume swards; in both cases the effect of the additional N source masks the effect of N supplied by mineralization of soil organic N. Some examples of resowing old grass to nil-N fertilized grass leys were given by Davies and Williams (1948) who reported increased cattle liveweight gain/ha in the year after sowing by amounts which ranged from as little as 5% (at a permanent pasture site likely to have been at equilibrium) to 50-100% on other sites.

Table 2. *Annual herbage DM yield and herbage N uptake from newly sown Lolium perenne swards without fertilizer N following cultivation of previously intensively managed ageing (5-12 year old) ley grass.*

Site	Herbage yield as t DM/ha year 1 and (mean of years 1-3)	Herbage N uptake as kg N/ha year 1 and (mean of years 1-3)
1 (N. England)	8.4 (6.8)	154 (131)
2 (N. England)	3.4 (2.5)	54 (41)
3 (SW. Wales)	8.7 (7.6)	141 (134)
4 (N. Wales)	2.7 (4.5)	38 (101)
5 (W. England)	3.5 (3.4)	66 (66)
6 (S. England)	4.4 (2.1)	74 (32)
7 (SW. England)	6.8 (6.1)	103 (104)
8 (S. England)	9.4 (4.8)	180 (95)

1.2.4 Soil N and environmental impacts

Increased nitrogen use has, without doubt, been a major factor contributing to the improved productivity of agriculture in temperate regions. The challenge facing farmers today is, however, to manage their swards in a way that minimizes the losses to the environment, whilst maintaining production. There are increased risks of leaching associated with grazed swards compared with cut swards (Ryden *et al.*, 1984), but even with swards managed primarily for cutting, ultimately the process of renewing the sward by cultivation releases large amounts of N which may not be intercepted by the newly sown grass crop. Shepherd *et al.* (2001) showed that the effect of spring ploughing for reseeding was relatively short-term (in contrast with repeated annual cultivations in arable rotations) and did not cause increased leaching in the following autumn, whereas autumn ploughing and reseeding leached between 60-350 kg N/ha. However, with both swards, losses in the next winter (when swards had been established for at least 1 year) were not different from undisturbed swards. The risk of leaching will depend on the amounts of N accumulated in the soil, the soil type and the timing and effectiveness in establishing a new crop. Another factor, which has been recently investigated (Stockdale *et al.,* 2002), is the role that nitrification has in promoting losses. Whilst mineralization of organic matter releases ammonium N, which is relatively immobile, nitrification generates the more mobile form as nitrate, which may be leached or denitrified. These authors found a strong correlation between leaching losses and the N saturation index (i.e. ratio nitrification : N immobilization). In instances where this exceeded a 1:1 ratio the soils became increasingly 'leaky'. An index derived from this ratio could be used to assess the recovery of soils taken out of agricultural production as one measure of sustainability. Decisions on cultivation timing also have other environmental implications other than N leaching, including effects on gaseous emissions, habitats for wildlife (e.g. winter feeding birds), carbon sequestration, landscape and soil erosion.

1.2.5 Phosphorus

There has been a long history of artificially increasing the phosphorus content of agricultural soils, particularly in those countries in Europe that industrialized early in the 19th century. The technology and infrastructure to produce and transport P-rich materials derived from bones, superphosphate, and industrial by-products such as basic steel-furnace slag, enabled soil P status to be increased and maintained to offset removal in crops and livestock products. In recent years, attention has focused on the environmental problems associated with high soil P status in limiting sward diversity (Jansens *et al.*, 1997) and in eutrophication of surface waters.

Impact of grass-to-grass resowing on herbage P uptake

In a multi-site trial, Hopkins *et al.* (1994) found herbage P concentrations were within a relatively narrow range, but that newly resown perennial ryegrass consistently and significantly had lower herbage P concentrations than identically managed permanent swards on adjacent plots (all treatments received 65 kg P fertilizer per ha/year, and had previously been raised to a common high soil P status). Since soil P was not limiting, these differences may relate to the capacity of different grassland species to capture soil P, or be the result of older swards having plant roots that are better developed to capture P.

Table 3. P in herbage (g per kg DM) in relation to sward type, fertilizer N rate and date of cut, mean of 16 sites in England and Wales (Hopkins et al., 1994)

	0 N fertilizers		300 kg fertilizer N /ha per year	
	Resown	Permanent	Resown	Permanent
May (1st harvest)	2.96	3.44	3.26	3.50
July (4th harvest)	3.23	3.35	2.92	3.03

Phosphorus dynamics in the context of grassland cultivations have received relatively little attention. Recent work at IGER (UK) has determined that losses of P can be classified under 'short' and 'long' term effects. In the weeks immediately following cultivation there is a physical detachment and consequent removal of P associated with soil particles and colloids, of particular significance on slopes under high rainfall conditions. The long term effects on P transfer (i.e. over a period of months) are the result of 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 mineralization through altered patterns of wetting/drying and increased soil aeration (Turner & Haygarth, 2001). In general, there is a lack of information on the effects of tillage on inorganic and organic P in soils.

1.3 Nitrogen and phosphorus cycling in grass-arable rotations

1.3.1 Soil organic N content

Nitrogen accumulates approximately linearly in young grasslands soils (<10 years), ranging from 20 to 130 kg N ha^{-1} $year^{-1}$ (Cuttle & Scholefield, 1995; Hassink, 1994; Hoogerkamp, 1984; Tyson *et al.*, 1990; Whitehead *et al.*, 1990). The rate of N accumulation depends on soil N content (low soil N content > high soil N content), management (high N input > low N input; grazed > cut), and age (young > old) but the separate effects of these factors can not be quantified yet due to lack of experimental data (Velthof & Oenema, 2001).

After conversion of grassland to arable land, N mineralization is enhanced and the organic N content will decrease in time until an equilibrium is reached for the arable soil. The time of this decrease in organic N content and the organic N at equilibrium situation strongly depends on the initial organic N content of the soil, nutrient management, soil type, weather conditions and crop type.

In temporary grasslands in rotation with arable crops, a period with N accumulation during the grassland period is followed by a period of net mineralization during the arable cropping period. The total N content is on average between that of permanent grassland and permanent arable land. Long-term studies in the UK (Figures 1 and 2) and France (Figure 3) clearly show the effect of land use system (permanent grassland, permanent arable land and grass-arable land rotation) on soil organic matter.

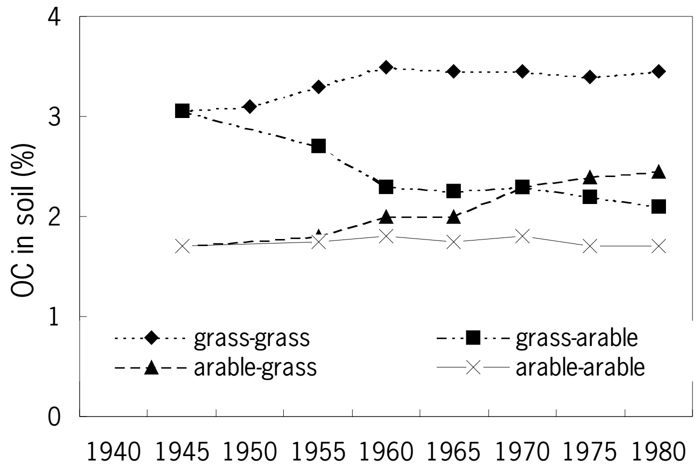

Figure 1. *Effect of ploughing out grass and sowing grass on soil carbon content. Data from the Rothamsted Ley-arable experiments (Johnston, 1986).*

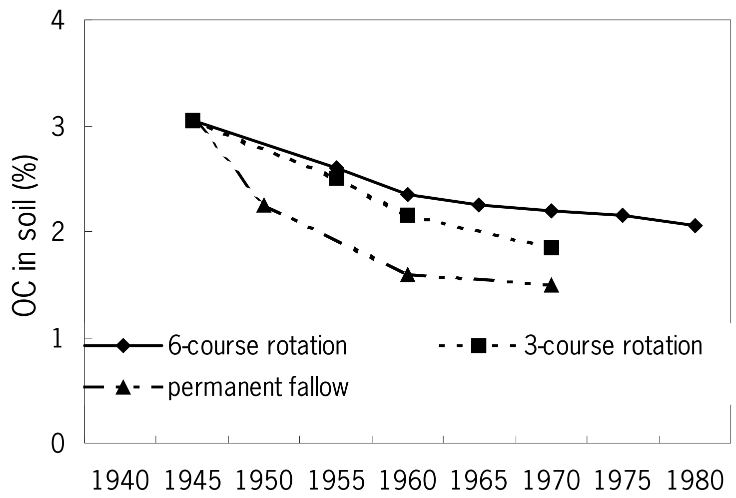

Figure 2. *Effect of three farm systems (rotations) on soil carbon content (from Johnston, 1986).*

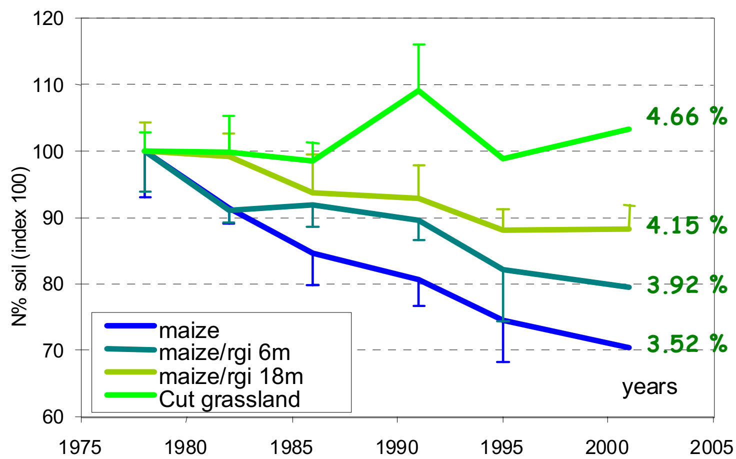

Figure 3. *Course of total N in soils in three rotations, including grassland vs maize + bare soil and maize + rgi (6 or 18 months); rgi is Italian ryegrass (Lolium multiflorum Lam.) (Simon, 1992; Vertès et al., 2001c).*

It may be hypothesized that in the long-term, the organic N content of the soil in rotations of grassland-arable land (see Figure 4) may: gradually increase (A); be in equilibrium (B); or gradually decrease (C). The change in soil organic N content may largely affect the N use efficiency and N losses of the system. Probably, situation C occurs after transformation of permanent grassland into grassland-arable land rotation and situation A after transformation permanent arable land into grassland-arable land rotation. Situation B indicate a long-term grassland-arable land rotation.

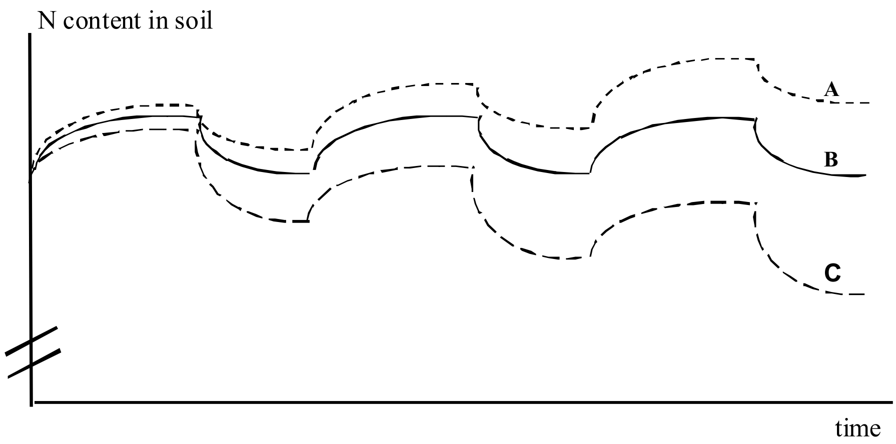

Figure 4. Schematic representation of the time course of the N content in the soil for temporal grasslands in rotation with arable crops. System A indicates a soil with a gradual increase in N content, system B indicates a soil with a stable N content and system C a soil with a gradual decrease in N content (Velthof & Oenema, 2001).

Major gaps in knowledge

The general pattern of an increase in soil organic N content in the grassland phase and a decreases in the arable phase are well-known and demonstrated in long-term field experiments. However, an accurate quantification of these fluctuations in N contents in different systems and soil types is required when N applications have to be tuned to the N demand of the crop in order to decrease N losses and maintain yields. Testing and validating of models with the experimental data of existing long-term experiments in different countries is a first step to derive a better quantification of the dynamics in soil organic N contents in grassland-arable land rotations.

1.3.2 Nitrogen contents in stubbles and roots of temporary grasslands

State of the art

In young grasslands, the N contents in roots and stubbles increases. Part of this N will return to the soil organic matter pool, but during the ageing process, the N content in roots and stubbles also increases. After conversion of grassland to arable land, this N is mineralized in the soil and because it is often easily mineralizable, it significantly contributes to the N supply to the following crop. On the other hand, when arable land is transformed into grassland, the N incorporated in roots and stubbles must be compensated by application of N fertilizer.

In the Netherlands, the amount of N in roots and stubbles in young grassland on sandy soil increased with about 150 kg N per ha during the first two years and only slightly increased in the period between 2 and 6 years (Figure 5, Van Dijk *et al.*, 1996). Whitehead *et al.* (1990) also showed a stronger increase of the amount of N in roots and stubbles in the first year after sowing (up to more than 100 kg N per ha) than in the years thereafter. Thus, the amount of N in roots and stubbles in young grasslands increases on average with 20 to 30 kg N per ha per year, with the highest accumulation in the first year (Davis et al., 2001; Van Dijk *et al.*, 1996; Whitehead *et al.*, 1990).

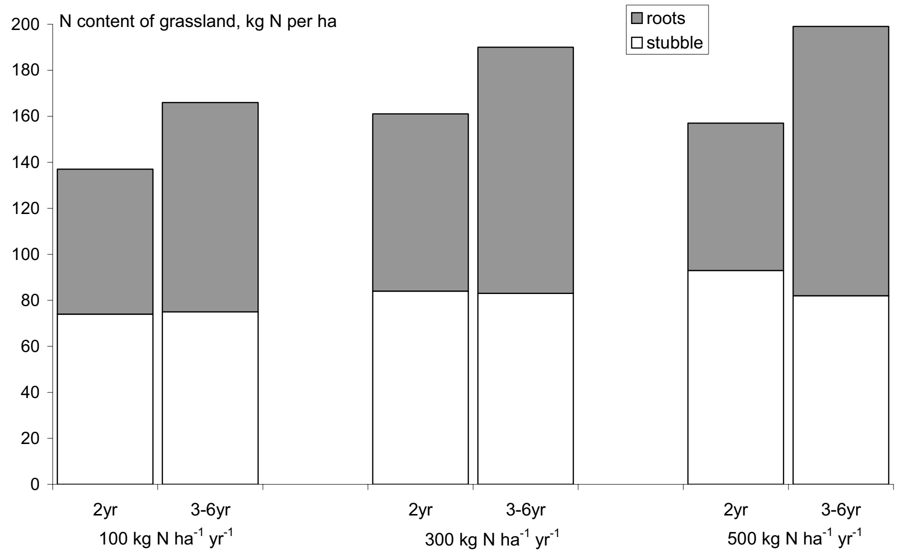

Figure 5. Amount of N in roots and stubbles in young grasslands (Van Dijk et al., 1996).

Major gaps in knowledge

Grassland management (fertilizer application and grazing) affect the amount and composition of roots and stubbles and thus the amount of crop residues incorporated when grassland is transformed into arable land. Adjustment of management in the grassland phase may therefore affect the N release in the arable phase. More insight is needed in the effect of grassland management and the amount and composition of roots and stubble.

1.3.3 Nitrogen mineralization

State of the art

Results in the literature show a wide range of total N mineralization rates in the first year after ploughing up temporary grasslands, ranging from 127 to 400 kg N ha^{-1} (Aarts *et al.*, 2001; Johnston *et al.,* 1994; Van Dijk *et al.*, 1996; Vertès *et al.*, 2001; Whitehead *et al.,* 1990; Zwart *et al.*, 1999;). These figures include both N mineralization from soil organic matter and from the ploughed in swards. The wide range is due to differences in experimental conditions (soil type, soil organic matter content, N management, sward age, crop type and management) and in the method of estimation of N mineralization (N balance, models, N uptake, and *in-situ* or laboratory incubations).

Huntjes (1971a & b) showed that the presence of plants had a negative effect on the net mineralization rate in soil samples of permanent grassland, using 15N labeling techniques. This immobilization was attributed to excretion of C-rich organic compounds by roots and by dead roots. The immobilization of added nitrogen was much larger in permanent grassland soils than in arable soil. The study showed that after killing the roots, the recently immobilized nitrogen was more rapidly mineralized than the 'older' soil organic nitrogen.

Studies of Lloyd (1992), Zwart *et al.* (1999) and Richter *et al.* (1989) indicate that there is no or only a small negative effect of the depth of grassland cultivation on N mineralization, soil mineral N contents and nitrate leaching.

Major gaps in knowledge

- There is a large amount of N mineralization data from various individual experiments conducted in different countries, but these data have not been combined and assessed. The wide range in reported mineralization rates is due to differences in experimental conditions (soil type, soil organic matter content, N management, sward age, crop type and management) and in the method of estimation of N mineralization (N balance, models, N uptake, and *in-situ* or laboratory incubations).
- Results of soil incubation studies in which potential N mineralization rates are measured in disturbed soil samples taken at one moment are difficult to translate into annual actual mineralization rates in the field on a per-hectare basis.
- 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. These methods should be tested in field experiments.
- Models can be used to predict N supply, but the models need input data (including the amount and composition of soil organic matter, roots and stubbles) and should be validated with experimental results.

1.3.4 Nitrogen leaching

State of the art

There are a number of studies in which nitrate leaching in rotations of grassland and arable land was quantified. The enhanced N mineralization increases the risk of N losses when the amount of mineralized N exceeds the N uptake of the arable crop. Leaving the soil fallow after ploughing of grassland resulted in very high leaching losses (100-300 kg N ha^{-1} yr^{-1}) (Adams and Jan, 1999; Davies *et al.*, 2001; Lloyd, 1992). Lloyd (1992) showed residual effects of grassland ploughing on leaching losses during the second winter, which is probably attributed to the fact that these arable soils were bare during winter.

The amount of N released and the risk on N losses increases with increasing age of the sward (Johnston *et al.*, 1994). The calculated N leaching losses ranged from about 100 kg N ha^{-1} after ploughing of a 1-year ley to 250 kg N ha^{-1} after ploughing of a 6-year ley.

Francis (1995) showed that sowing a cover crop during winter decreased N leaching by up to 60 percent. Francis (1995) indicated that a delay in ploughing grassland and conversion to arable land from autumn to spring decreased N leaching losses with 10 to 50 kg N ha^{-1} yr^{-1}**.** However, Lloyd (1992) indicated that postponing ploughing from autumn to spring may increase leaching losses in the second winter, though growing cover crops during winter may decrease N losses.

The impact on nitrate leaching of methods of ploughing, or otherwise moving from grass to arable crops, was tested in the UK in field trials at Coates Farm, Cirencester (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 losses were relatively small compared with the 100-300 kg ha^{-1} given above. Thus, the impacts of ploughing out grass on the environment can be alleviated by good management practice.

In Denmark, Eriksen *et al.*, (1999) showed that in an organic dairy crop rotation nitrate leaching was highest in the second winter (after winter wheat) following ploughing, and leaching losses were lowest in first year grass/clover (Figure 6).

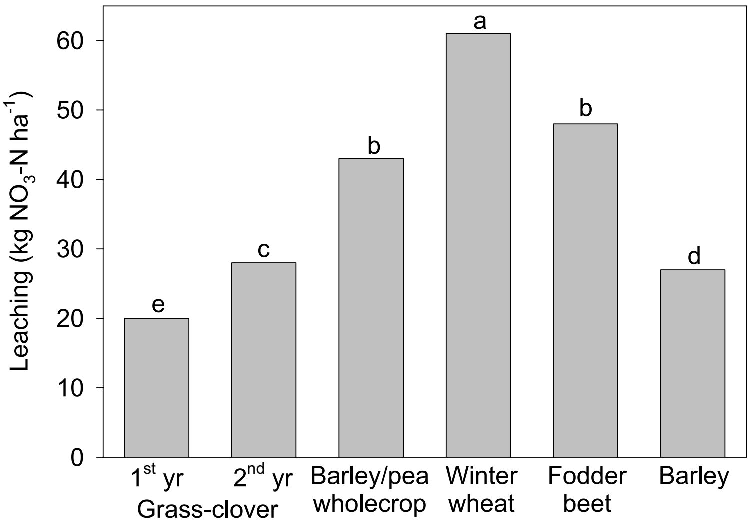

Figure 6. Nitrate leaching from an organic dairy crop rotation on loamy sand as average of 1994-1998. Bars with the same letter are not significantly different (P<0.05) (Eriksen et al., 1999).

On a dry sandy soil in the Netherlands, Conijn (2000) reported average nitrate concentrations of 55 mg l^{-1} under a grass-maize rotation, with lower leaching losses during the grass phase than during the maize phase (Table 4). In the same period, the average nitrate concentration under permanent grassland was 53 mg l^{-1}.

Table 4. Average NO_3 concentration in ground water in a sandy soil at De Marke in the Netherlands for different crop rotations (Conijn, 2000). The management of grassland and maizeland was focussed at high yield and low NO_3 leaching.

Crop	Average NO_3 concentration in mg l^{-1} in 1993-1998[1]
Permanent grassland	53 (41-84)
Grassland, 1st year[2]	76 (43-127)
Grassland, 2nd year	43 (16-66)
Grassland, >2nd year	33 (27-45)
Maize, 1st year[3]	47 (9-177)
Maize, 2nd year	67 (13-139)
Maize, >2nd year	63 (30-115)

[1] *Values in parentheses show the range.*
[2] *NO_3 in ground water under the 1st year of grassland is leached from maize land in the year before*
[3] *NO_3 in ground water under the 1st year of maize land is leached from grassland in the year before*

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 in Denmark (Djurhuus & Olsen, 1997). The results showed that winter wheat did not have the potential for taking up the mineralized 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.

The residual effects of six different temporary grassland fields on yield and nitrate leaching were investigated in Denmark for three years after ploughing. The grassland fields were unfertilized grass/clover and fertilized ryegrass subjected to cutting or continuous grazing by dairy cows with two levels of N in feed supplements (Eriksen, 2001; Eriksen & Søegaard, 2000). 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 minimize nitrate leaching (Figure 7). Annual mean nitrate concentrations in unfertilized 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.

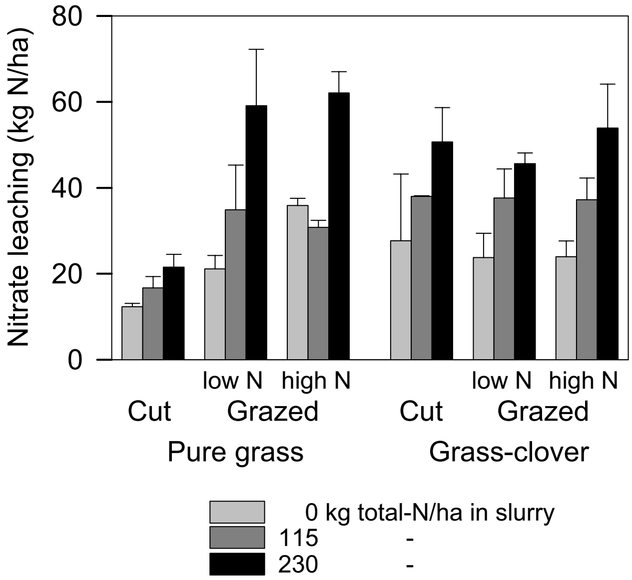

Figure 7. Nitrate leaching in cereals in year 1 following ploughing of six grassland fields on loamy sand. Low and high N refers to 140 and 300 g N cow^{-1} d^{-1} in supplements to dairy cows (corresponding to approx. 230 and 320 kg N ha^{-1} $year^{-1}$ excreted in the field). Error bars: SE. (Eriksen, 2001; Eriksen & Søegaard, 2000)

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 minimize 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).

Major gaps in knowledge

- In several countries, N leaching data are available, especially for the period after ploughing grassland. Combination and synthesis of these data may give an improved insight into N leaching in grass-arable rotations.
- System analyses are needed to evaluate the whole system of grass-arable rotations from both environmental and agricultural point of view. Relatively high losses in the arable phase may be compensated by low losses in the grassland phase. For these system analyses, data of both permanent grassland, permanent arable land and grass-arable rotations are required.
- 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 mineralized in the soil, but may also leach to ground- and surface waters, where it can be mineralized 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.

1.3.5 Gaseous losses

State of the art

There is little information available on gaseous losses from organic farming systems. In a study in the UK, 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).

Results of a study by Davies *et al.* (2001) in the UK showed that ploughing of grassland increased N losses via leaching, N_2O emission and denitrification when the soil was left fallow. Ploughing followed by reseeding considerably decreased N losses, and especially from denitrification. The N leaching losses were much higher than those via N_2O emission and denitrification.

Nitrous oxide emission in the Netherlands show high emissions after ploughing grasslands, especially during wet and relatively warm periods in summer.

Major gaps in knowledge

- Nutrient management should be aimed at decreasing total N losses and avoiding transferring one pathway of N loss to another, e.g. replacing N leaching with denitrification. However, gaseous losses via denitrification and N_2O emission in grass-arable rotations are poorly quantified. There are only a few studies in which these gaseous losses were quantified.
- Emission of ammonia is mostly related to manure, grazing and ammonium fertilizer application on calcareous soils. However, some production of ammonia may occur during degradation of crop residues, especially during anaerobic conditions. It is unknown whether ammonia emission from ploughed grassland is a significant source of N loss.
- 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.

1.3.6 Mineral N in soil profile

State of the art

Johnston *et al.* (1994) determined the nitrate content in the 0-90 cm layer of sandy loams in October, three months after ploughing grassland in summer. The nitrate contents in the soil amounted to 93, 122, 204, 199, 201, and 230 kg N ha^{-1} for grassland of 1, 2, 3, 4, 5, and 6 years, respectively. These results indicated no or little increase in nitrate content in the soil for grasslands older than 3 years.

A study in Belgium (Mertens, cited in Nevens *et al.*, 2002) showed high residual soil nitrate-N (0–90 cm) after harvest of maize, grown after ploughing grassland (Table 5). The experimental results showed that it was only possible to remain under 90 kg nitrate (a limit set in Belgium) when no fertilizer N was applied to the silage maize following the ploughed grassland. In the case of location 3 (wet soil) it was impossible, also without any fertilizer, to stay below this limit.

Table 5. Survey of nitrate (kg N ha^{-1}) in the soil profile (0-90 cm) in maize land, after ploughing grassland in January and April (Nevens et al., 2002).

Time of sward destruction	Nitrogen fertilization (kg N ha^{-1})	NO_3-N (kg N ha^{-1})		
		Location 1	Location 2	Location 3
January	0	49.9	87.1	197.8
January	150	240.6	195.3	312.7
April	0	61.5	32.6	188.5
April	150	136.7	246.3	233.3

Major gaps in knowledge

Mineral N contents in the soil profile at the end of the growing season are relatively easy to measure and give an indication of the amount of N which is expected to be lost during the winter. However, translating mineral N contents in N leaching and gaseous N losses is difficult, because the ratio between N leaching and gaseous losses is strongly influenced by soil type, weather conditions and crop species.

1.3.7 The following crop

State of the art

After cultivation of grassland, growing arable crops with a high N uptake capacity will decrease the risk on N losses to the environment. Research in Belgium shows that very low, or even no N fertilizer 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 fertilizer 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.

In Table 6 crops are categorized according to their N demand calculated from N fertilizer recommendations in the Netherlands. The N demand indicates the total amount of available N required to obtain optimal yields. This amount includes the amount of soil mineral N in spring, the amount of N from mineralization, the atmospheric deposition during the N uptake period of the crop, and the amount of available N applied via fertilizers. Crops with a relatively low N demand (i.e. < 150 kg N ha^{-1}) are asparagus, bunched carrots, carrots, and witloof chicory. Crops with an N demand higher than 250 kg N ha^{-1} are blanched celery, broccoli, Brussels sprouts, cauliflower, Italian ryegrass, kale, leek, perennial ryegrass, pickling cucumber, potato, red cabbage, savoy cabbage, silage maize, spinach, winter wheat and white cabbage. Most other crops have an N demand between 150 and 250 kg N ha^{-1}.

Crops which are harvested relatively early, such as silage maize and potato, can be followed by a winter crop to absorb residual mineral N. Under Dutch conditions, Italian ryegrass, winter rye and fodder radish are the most suitable crops for this purpose. Their N uptake will be about 40 kg ha^{-1} when the main crop is harvested on 21 September, whereas earlier or later harvesting of the main crop will increase or reduce this value with ca. 2 kg N ha^{-1} day^{-1} (Schröder, personal communication).

Table 6. Classification of crops in terms of their N demand calculated from fertilizer recommendations in the Netherlands (Velthof et al., 2002)

N demand, kg N ha^{-1} yr^{-1}	Crops
< 200	Asparagus, Bunched carrots, Carrot, Witloof chicory, Radish, Scorzonera, White radish
200-250	Headed lettuce, Iceberg lettuce, Kohlrabi, Onion, Parsley, Endive, Sugar beet, Chinese cabbage, Beetroot (red beet), Strawberry, Swede, Turnip-rooted celery, Dwarf French bean, Fennel
250-300	Blanched celery, Pickling cucumber, Silage maize, Brussels sprouts, Spinach, Winter wheat, (curly) kale
> 300	Broccoli, Cauliflower, Italian ryegrass, Leek, Perennial ryegrass, Potato, Red cabbage, Savoy cabbage

Results of measurement in Germany show that growing an understorey in maize decreases N leaching (Figure 8).

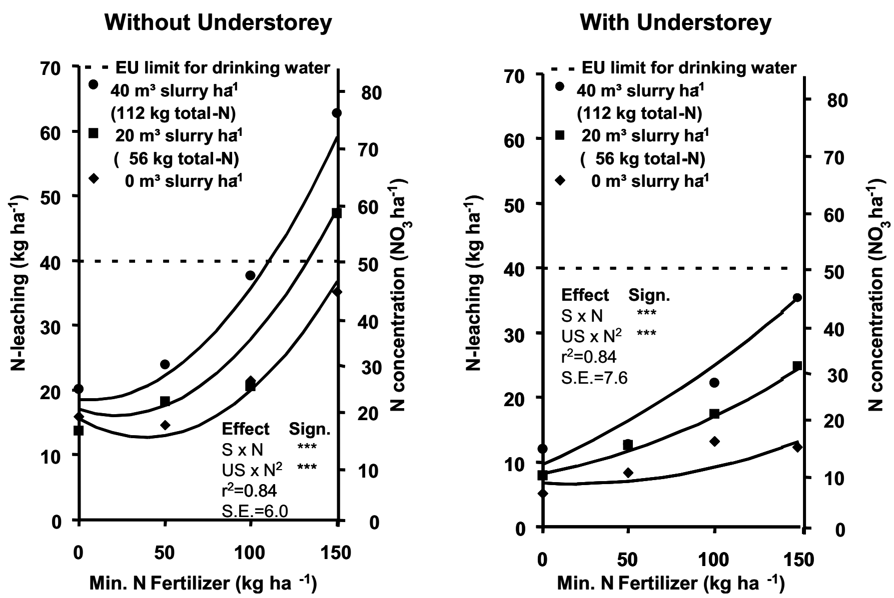

Figure 8. Nitrate leaching losses (kg N ha^{-1}) under maize for silage (S: slurry; N: mineral N fertilizer, US: understorey) (Büchter et al., 2001).

Model calculations of Brisson *et al.* (1998) in France showed that after ploughing of grassland, 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% for 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, rapid mineralization is to be expected (Nicolardot *et al.*, 2000, Trinsoutrot *et al.*, 2001). Morvan *et al.* (2002) measured a mineralization 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.

The high net N mineralization 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 fertilizer application rates.

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.

Gaps in knowledge

System analyses are needed to evaluate the agronomic and environmental consequences of type of arable crop in grass-arable rotations, both in dairy farming systems and arable farming systems.

1.3.8 Effects on phosphorus

State of the art

- Little attention is paid to phosphorus dynamics in grassland-arable land rotation studies. For renovation of permanent grassland, short term (i.e. transport of P with soil particles) and long term (i.e. leaching of soluble P) effects of cultivation of grassland on N leaching were mentioned. These effects will probably also hold for grassland-arable rotations, but more research is required to quantify the P losses after transformation of grassland into arable land.

1.3.9 Management options to decrease nutrient losses

State of the art

In a literature review, Velthof & Oenema (2001) concluded that the risk of N leaching after ploughing of grassland increases:
- with increasing grassland age;
- with increasing time between cultivation and reseeding grassland or sowing arable crops;
- when the N uptake capacity of the preceeding crop (including a cover crop) decreases, i.e. the total N uptake and the period of N uptake;

Thus the smallest risk of N loss occurs when young grassland is cultivated and directly reseeded in spring and the largest risk occurs when old grassland is ploughed and left fallow for a prolonged period.

There are several possibilities to decrease the risk on N leaching after ploughing of short-time grassland in rotation:
- Low or zero N applications, or restricted grazing in the year before grassland is ploughed (because this will decrease the amount of N in roots and stubble and the amount of N released after ploughing).
- Postponing cultivation of the temporary grassland from autumn to spring (e.g. Francis, 1995; Djurhuus & Olsen, 1997);
- Adjustment of N fertilizer application to the expected N mineralization from ploughed grassland (e.g. Conijn, 2000);
- Growing cover crops (e.g. Francis, 1995);
- Growing crops after ploughing of grassland that have a high N uptake and a long uptake period, such as fodder and sugar beet (e.g. Conijn, 2000).
- Other measures, including overseeding, permanent understorey (bi-cropping), strip cropping (strips of grassland and arable land in one field), and buffer strips (no ploughing near rivers and ditches).

Major gaps in knowledge

In general, there are ideas and results about management options to decrease nutrient losses from ploughed grassland, but the effectiveness of measures is strongly dependent on local conditions, including soil type, management, weather conditions, time and type of grassland cultivation, and following crop. The challenge is to develop a widely applicable scheme with possible measures to decrease nutrient losses from grass-arable rotations under different conditions.

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Theme 2.

Soil quality and water balance

2. Effects of grassland cultivation and ley-arable rotations on soil quality

F. Vertès[1], S. Abiven[2] & P. Loiseau[3]

[1] INRA UMR SAS, 4 rue de Stang Vihan, 29000 Quimper (Francoise.Vertes@rennes.inra.fr)
[2] INRA UMR SAS, ENSAR, 65 rue de Saint Brieuc, 35042 Rennes cedex, (abiven@roazhon.inra.fr)
[3] INRA FGEP, 234 avenue Brézet, 63039 Clermont-Ferrand (loiseau@valmont.clermont.inra.fr)

2.1 Introduction

From a practical point of view, soils highly contribute to several environmental functions: plant production of sown or spontaneous species communities, nutrients and water cycle (soil fertility, water and atmosphere quality), conservation of biodiversity (plants, micro-organisms and mesofauna). In the previous meeting in Wageningen, the soil quality group mentioned that the demands of society regarding soil quality were sometimes conflicting, opposing mainly cheap food production to the maintenance of high biological and landscape diversity. As an absolute definition is probably impossible, soil quality is often evaluated by indicators (Singer & Ewing, 2000) that must give right ideas of soil functions. Such indicators reflect soil processes, that integrate physical, chemical and biological properties, whereas the processes themselves are difficult to measure and quantify in field conditions. They must be as simple, precise and reliable as possible. To illustrate with a practical example, for most animal breeders, the main criterium of a good grassland is a good bearing capacity, which means that animal herds can graze throughout most of the year without inducing heavy damage to plant and soils.

One characteristic of grasslands is their wide distribution on soil types and climate. We exclude here the situations where only permanent grasslands can develop (natural or maintained herbaceous by animal grazing), and concentrate on the ploughable situations, with short (2-3 years) to long (until 15 years) duration grasslands. When management is adapted to agronomic potentialities, one can consider that a dynamic equilibrium between plants, soils and animals allows a high persistency of grasslands and a high soil quality: from physical, chemical and biological points of view, grassland soils would probably present a level of quality higher than almost all other cultural systems. Thus, the question of grassland soil quality could be referred to two groups of situations relative to grassland rotations: (i) the strong and sudden decrease of soil quality when grassland is ploughed for resowing and (ii) the ability of the grassland systems to restore a high level of soil quality. It refers not only to the level of fertility and environmental control at a given time, but also to the time dynamic these functions are restored.
Evaluation of grassland soil quality is focussed in this paper on the main topics discussed during the Wageningen meeting (report 57) : level of grass production along time, regulation of the water (drainage), carbon and nitrogen fluxes. Section 2.2 presents the synthesis of the report, section 2.3 is focussed on soil structure and section 2.4 concerns C & N storage / mineralization from the short to the long term.

2.2 How soil quality components were defined in the previous country reports

Table 1 sums up the reasons presented in the Wageningen report country synthesis for grassland cultivation. The main one is a non-satisfying evolution of botanical composition, via replacement of highly productive perennial ryegrass by grasses of lower interest, such as Agrostis or Poa species, or via infestation by weeds (Rumex acetosa, Elymus repens or Ranunculus sp), inducing lower production and lower feeding value for the animal (apetability, digestibility/intake and forage value). Soil compaction is put forward just after in most of the countries, accompanied by linked reasons, such as poaching and treading damages, which decrease N fertility through a lower rooting ability.

Table 1. Reasons and criteria quoted to cultivate grasslands in Wageningen report 47 (Conijn et al., 2002).

	NL	B	UK	DK	D	F	IRL
Botanical composition (including use of improved varieties)	+ (<50% *Lp*)	+	+	+ (clover decrease)	+	+ (clover decrease)	+ (<40% *Lp*)
Weed invasion	+ (Elymus repens)	+ (docks, E. repens)	+ (docks)		+ (docks)	+ (docks)	+ (docks)
Ley-arable benefits or ley-arable systems	+	+	+ (5 years)	+ (3 years)	+	+	+
Production decrease	+	+	+		+	+	+ (silage)
Soil compaction	+	+	+		+	+	
Herbage quality	+			+	+		+
Poaching or scorching damage	+		+				
Decrease in soil N nutrition		+				+	
Pests and diseases	+			+			
Low root ability	+ (high N)						
Delay for silage	+ (high N)						
Frost damage	+ (high N)						

The thematic discussions led to the synthesis, presented in Table 2. Most of these factors are, more or less directly, linked to degradation of soil structure by compaction due to animal treading and/or heavy silage machines used in wet conditions. The most intensively managed grasslands seem the most sensitive to degradation (NL), but it concerns nearly all the situations. Main consequences of treading damage are well known: low production during recovery, degradation of the botanical composition by weed infestation (e.g. *Poa* spp. and *Agrostis stolonifera),* extension of bare soil patches, lower production and herbage quality due to decreased nutrients availability, superficial rooting, decrease of the water reserve and of the drainage speed… etc. Moreover treading damage also concern macrofauna such as earthworms (Cluzeau *et al.*, 1992), with consequences on water circulation in soils. Besides direct plant destruction, all those perturbations concern modification of soil structure and porosity.

Parameters	Permanent grasslands	Grass-arable farming	Arable crops
C storage and release			
Soil structure			
Soil fertility (nutrients/ pH)			
Biodiversity (flora, fauna, microorganisms			

As influenced by soil type and climate

With different objectives of social requirements - CAP - farmers

Table 2. Current knowledge gaps in four major soil quality topics for three cropping systems.

2.3 Soil structure

2.3.1 Aggregation dynamics under grassland

Six *et al.* (2002) proposed a model of macro-aggregate formation and breakdown that differs for tilled and not-tilled soils. According to this concept, new micro-aggregates resulting from the decomposition of particular organic matter gather with older ones to form macro-aggregates. Differences between tillage and no-tillage consist in a higher micro-aggregate proportion in non-tilled system macro-aggregates (47% of the weight) than in tilled system macro-aggregate (27% of the weight). Authors assume significant differences in macro-aggregate structural stability and turn-over in the two systems. From a certain point of view, grassland could be seen as a non-tilled system which receives important Particulate Organic Matter inputs of a very large quality range. The dynamics of aggregation under grassland are probably the center of an important part of the soil quality regulation and should be better estimated.

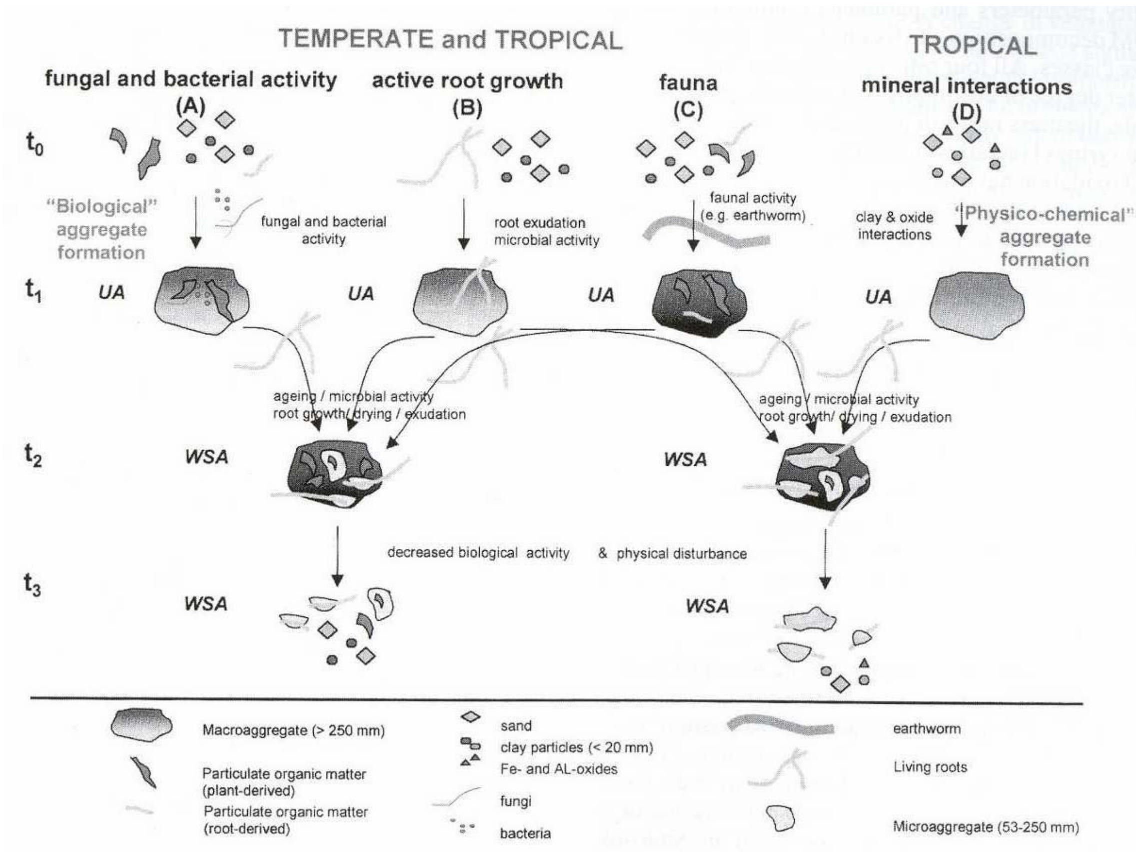

Figure 1. Soil aggregation dynamics (Six et al., 2002).

This structure is due to native soil materials reacting with organic inputs (Six *et al.*, 2002). One characteristic of grassland plants is their root abundance, representing 7 to 12 t DM.ha^{-1} (Whitehead, 1992 ; Conijn *et al.*, 2002). Root exudates allow a high microbial activity in the rhizosphere. In addition, root turnover and rhizodeposition introduce in the soils an important amount of residues, which accumulate in soils. Whatever their location, near the surface or in the deep soil, these OM input are protected from degradation in stable aggregates. Roots play a major role in both soil structuring and OM input, as it was proposed previously by several authors (Tisdall & Oades, 1982), but stay still little studied until today. In turn, a well-structured soil allows i) a good rooting, thus plant alimentation in water and nutrients (N, P…) and a better resistance to treading damage, and ii) a good drainage capacity that limits the duration of water saturation periods.

2.3.2 Effects of cultivation and grassland renovation on soil structure

Grassland ploughing has considerable effects on soil organic matter dynamics. Besides the mineralization and immobilization of nutrients, the subsequent decrease of soil organic matter 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 3). 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 increase in water availability is an important advantage. In later years, roots, organic matter and nutrients concentrate in the top layer of 0-5 cm.
On clay and peat soils, the physical qualities of the soil, such as soil aggregate stability and bearing capacity are generally negatively affected at 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 3. The estimated effect of soil quality changes, due to grassland renovation (Schils et al., 2002).

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	–/–
Leveling	+	+	+/++	0/+	+
Rooting capacity	++	0	+	++	+
General	+	–	+/0	+	++

2.3.3 Biological activity as affected by soil cultivation and ley-arable rotations

The consequences of treading on soil compaction and plant damage were studied a long time ago (Brown & Evans, 1973), or more recently on soil, plants and earthworms (Vertès *et al.*, 1991, Cluzeau *et al.*, 1992). Fewer attempts to quantify and model microbial activity were done in grassland soils (Garland & Mills, 1991; Chaussod *et al.*, 2002).

Concerning earthworms, recent studies have shown correlations between the type of the pasture and the associated macro-fauna. Pérès *et al.* (2002) observed significant differences between abundance and structure of the earthworm populations in an old pasture and in a pasture which was integrated in a short arable-grass rotation. On the same site, Lamandé *et al.* (2001) observed that, if the whole porosity was roughly equivalent in all the cases, important and significant differences were obtained on pore characteristics and, as a consequence, on hydraulic conductivity. Measurements show a decrease of the packing voids forming the porosity between new and old pastures (mainly due to trampling during grazing) and more important conductivity for the renovated grassland in (near) water-saturated soils. They conclude that packing voids appeared to be a good indicator of beneficial effects of biological activity on hydraulic conductivity, this beneficial effects being reduced in soil compacted by animals.

As well, fewer studies showed the microbial community is affected by soil management. Garland & Mills (1991) showed that during grassland life there were large differences in functional diversity as compared with arable crops, and that cultivation decreased significantly the microbial diversity. Nevertheless, microbial communities can develop strategies, that cope with soil disturbances and, as for heavy metal toxicity (Chaussod *et al.*, 2002), they may probably be less sensible to stress than macro-fauna.

2.3.4 Conclusion and lack of research

Whereas the negative effects of heavy soil compaction on plant growth, earthworms and micro-organisms activities are well assessed, the soil capacity to resist to compaction or to recover previous porosity and the associated processes is not yet well known. Moreover, some indirect positive effects of grassland cultivation on following crops, such as a better resistance against fungal diseases (Eriksen, 2001) may be partly linked to soil structure modifications.

When treading or scorching damage include bare soil patches, the way is opened for infestation of annuals or resistant species such as *Elymus repens*. Integration of risk at field level and infestation dynamics are not well known neither the ways to prevent it (except avoiding high stocking rates and grazing in wet conditions). Very high fertilization level would increase the risks of soil structure degradation through a more superficial rooting system, high instant stocking rates and frequent grazing cycles/harvests with lower flexibility with regard to soil-climate conditions. A better knowledge of mechanisms (constitution and degradation of soils aggregates, …) and thresholds could help to reduce grassland degradation and cultivation frequency in grass based systems. Among them, one of the main components of soil structure is soil organic matter. The next section will thus consider C fluxes.

2.4 Carbon sequestration and mineralization in grassland soils

Several factors contribute to C dynamics characteristics under grassland (INRA Expertise, 2002):

- the main incorporation of organic inputs is through root systems (exudates and dead roots), that stimulate C storage because their location in the soil matrix allows a good physical protection (Balesdent & Balavoine, 1996; Six *et al.*, 2002);
- the level of organic input is high, due to sward perennity and to a high belowground growth allocation;
- the root phytomass, as well as the amounts of particulate organic matter derived from the root litter, usually increase during several years, as grassland ages;
- the OM inputs from grassland are generally more resistant to degradation than those from annual crops, because they are richer in lignin and in aromatic compounds, especially in case of legumes;
- in the absence of soil tillage the fermentescible part of the fresh organic matter stimulates the microbial biomass and activity, which stimulate aggregation and soil structural stability. In turn, the protection of SOM allows C storage;
- protection results not only in a slow rate of root litter transformation, as compared to tilled soils, but, at similar rate of litter transformation, also in a lower part being mineralized into CO_2 and thus a greater part sequestered in the soil. Therefore, litter dynamics differs by a lower rate as well as by a lower yield of mineralization;
- this results in the accumulation of debris derived from root litter: in a continuum, litter-C accumulates in root debris of decreasing particle size, whose residence time increase in that order, as shown by ^{13}C labeling experiments (Loiseau & Soussana, 1999).

These characteristics found an expression through different mechanisms and process in the soil.

2.4.1 Effects of grassland cultivation on C mineralization

Mid- to long-term C mineralization

The effect of grassland destruction on C stock evolution is well documented. Tillage decreases the protection of previously accumulated litter and SOM by aggregate destruction and soil aeration. Not only the transformation rate of this grassland-derived SOM is accelerated, but also a greater part is mineralized. Moreover, the C input of the new crop is lower of which a great part is mineralized.

Conversion of grassland to arable land usually causes a strong release of soil C. Strebel *et al.* (1988) measured a decrease of about 100 t Corg ha^{-1} (-57%) for a period of 4 years after grassland conversion, whereas SOM quality remained unchanged. Eriksen & Jensen (2001) measured losses of 2.6 t C ha^{-1} during the 3 months following cultivation of 3 year old grassland, compared to 1.4 t C ha^{-1} in the undisturbed control. Loiseau *et al.* (1996) measured 2.5 to 3 t C ha^{-1} y^{-1} as CO_2 during 3 years following destruction. French expertise (INRA Expertise, 2002) on C budgets evaluated the losses of C after sowing at 2.8 t C ha^{-1} y^{-1} for seeded grassland and 3.2 t C ha^{-1} y^{-1} for perennial grassland. The decrease is stronger just after ploughing, but is still important after twenty years (Figure 2).

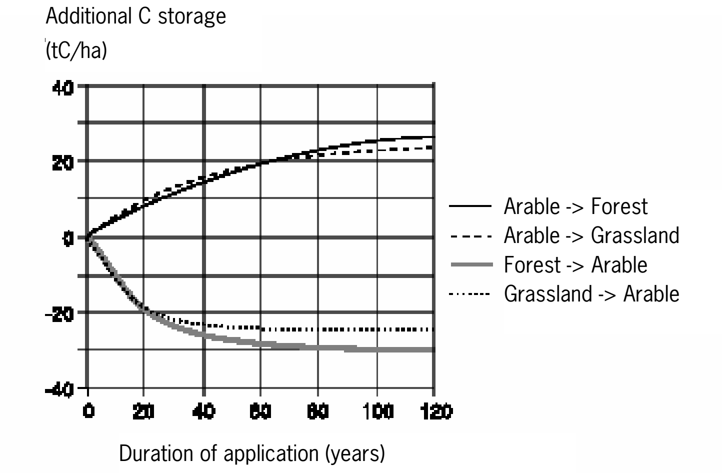

Figure 2. Evolution of soil C stocks when land use or agricultural practices change (INRA Expertise, 2002).

Johnston *et al.* (1986) showed that C accumulated under grass and that mineralization prevailed under arable crops (Figure 3). In grassland, the C dynamics were affected by grass age (in Hatch *et al.*, 2002). The main finding was that soils that had supported arable crops over a long period and remained to do so, maintained constant OC contents, whereas soils that were ploughed out from grassland and put into continuous arable cropping steadily lost OC. Soils in permanent grass continued to gain OC; soils sown to grass from an arable history slowly gained OC, 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 under continuously tilled soil; lucerne did not increase OC. Ploughing up arable land reduced 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 3. Permanent fallow 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. Similar dynamics were observed other countries (Strebel *et al.*, 1988 ; Vertès *et al.*, 2001) on long term survey, and in the recent French synthesis data concerning carbon storage ability of different agricultural systems and practices.

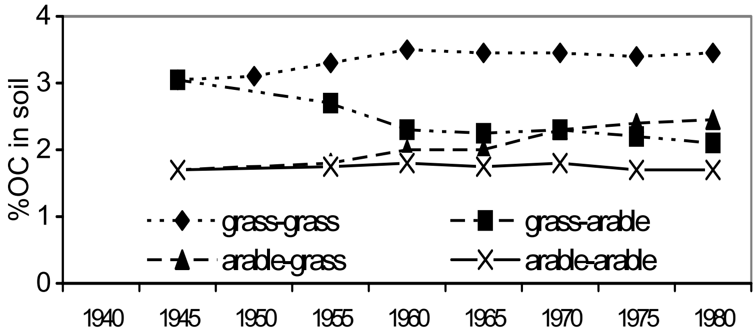

Figure 3. *Effect of ploughing out grass and sowing grass on soil carbon content. Data from the Rothamsted Ley-arable experiments (Johnston, 1986).*

C storage appears less efficient than C mineralization, as pointed in the Table 4 that indicates scales values of C fluxes (synthesis on French conditions, Loiseau in INRA, 2002).

Table 4. *C dynamics in permanent grassland and arable crops.*

A is permanent grassland B is crop	A → B	B → A
Mean C stock at equilibrium for A (t C ha^{-1})	65 *(5)*	40 *(5)*
Mean C stock at equilibrium for B (t C ha^{-1})	40 *(5)*	65 *(5)*
Mineralization rate (y^{-1})	0.07 *(0.01)*	0.025 *(0.01)*
Annual fluxes for C storage (t C ha^{-1} y^{-1})	-1.7 *(0.8)*	0.63 *(0.36)*
Annual fluxes for C storage on 20 years (t C ha^{-1} y^{-1})	-0.95 *(0.3)*	0.49 *(0.26)*
Annual fluxes IPPC 2000 (t C ha^{-1} y^{-1})		0.8

Carbon accumulation is half as slow as the carbon release occurring after the grassland is ploughed, in agreement with other long term observations, but no simple model is available until now to generalize those results for grassland C fluxes.

Short term effects of grassland destruction

Direct measurements of 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 month after cultivation compared to only 1.4 t ha^{-1} emitted from the untilled soil (Eriksen & Jensen, 2001). Vertès *et al.* (2001) measured in incubated soils a C mineralization varying from 400 to 500 mg C-CO_2.kg^{-1} dry soil for 'bare soils' and from 900 to 1100 mg C-CO_2.kg^{-1} dry soil for soils having received fresh plants residues in the same proportions as in a destroyed grassland. Those high values for short term losses demonstrate that a great part of the OM that is protected and that accumulates during grassland life remains highly degradable.

2.4.2 Storage of C in a new grassland

The conversion of arable land into grassland has a positive effect on C stock. Estimation of the C content increase ranges between 0.3 to 0.8 t C ha^{-1} y^{-1} during 50 years for GIEC (2000) to 0.6 +/- 0.14 t C ha^{-1} y^{-1} during 30 years for French expertise (INRA Expertise, 2002). Variations are assumed to be caused by climate variability, grassland management, differences in sampling procedures and the initial soil C content. However, soil texture does not seem to explain the variability in the French study. Moreover, Reeder *et al.* (1998) observed faster sequestration under grassland in sandy soils than in soils rich in clay. In a crop rotation experiment, Søegaard (1988) 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. This increase was not followed by a similar increase in soil organic N. 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 contents of soils from a very low base value of 0.7 - 1.0% by amounts up to 0.2% (Johnston *et al.*, 1994). There is a higher N and C accumulation in clay soils than in sandy soils, due to the better protection of organic matter in clay soils, and in soils with high vs low groundwater tables.

The duration of C accumulation under grassland is also controversial. After 50 years, C stock only reached 50% of the content the soil had before the ploughing (Rasmussen *et al.*, 1998). Contrarily, Frank (2002) observed that 20 year old pastures could not be considered anymore as a C sink.

More generally, unexpected results could result from the unit used in expressing C dynamics. As C accumulation is exponential, the correct units to express C accumulation should be the relative rate of C accumulation (y^{-1}). This expression allows to calculate any soil C increase on an area basis, knowing the initial soil-C and the potential C accumulation for the given grassland environment and management. To avoid confusion, this method was already used in the French expertise for carbon sequestration in agricultural, grassland and forest soils.

Indeed, the major impact of the conversion to grassland is the higher yield of biomass production that exists under pasture. Lal & Bruce (1999) estimated the increase of C content in soil due to grassland following arable land by 0.4 - 1.2 t C ha^{-1} y^{-1}, while it was only 0.6 - 0.9 t C ha^{-1} y^{-1} when the land use after arable land was less productive than the pasture. The ability of the pasture to sequestrate C is directly linked with its life length. It is assumed that half of the C accumulation potential is reached after 6 years (between 4 and 11 years, INRA Expertise, 2002).
In fact, C is sequestered in SOM compartments of different residence time and total soil C accumulation is the sum of several exponential dynamics. Maximum C accumulation is obtained successively for SOM compartments of increasing residence times, That corresponds to specific processes of OM transformation and to specific SOM quality.

2.4.3 Soil organic matter quality

As mentioned before, the intrinsic quality of the SOM is particular under grassland. Moreover, much variation is related to the grassland type. Several reports (DK, IRL, UK) noticed the relation between the characteristics of the SOM and grassland management/age influence herbage composition through the ratio leaves/stems/roots and in the chemical composition of plants parts. Much variation in the litter quality is caused by the botanical composition, mainly the relative abundance of competitive versus conservative species. Variation in litter quality and consequences for C sequestration are summed up Table 5.

Table 5. Main characteristics of C dynamics parameters compared in the six main fodder systems (INRA Expertise, 2002).

	Pure grass highly fertilized	Pure grass moderate fertilization	Grass/legumes or legumes without N	Intensive grassland grazed or cut	Extensive grasslands grazed or cut	Permanent swards or meadows
Age (years)	1-2	1-2	3-12	5-15	5-15	permanent
Inputs amounts	2[1]	3	4	4	3	4
Inputs quality						
N concentration	5	4	3	3	2	1
Fermentescibility	5	4	3	3	2	1
Mineralization coef.	5	4	3	3	2	1
Humification way[2]						
Microbial way	3	4	5	4	3	2
Detritic way	1	1	2	3	4	5
Humification coef.	1	2	3	3	4	5

[1] *Values range from from 1 (very low) to 5 (very high).*

[2] *Way of humification: two pathways by which C is stabilized in the SOM are considered: through microbial transformation (neoformed humus) and through plant detritus transformation (inherited humus). The humification coefficient represents the yield of C input in humus-C, the complement being mineralized into CO_2.*

Relation between SOM and C and N mineralization

Soil respiration in different cropping systems has been found to depend on total soil C. Nevertheless this relation is week. More variation can be accounted for, by distinguishing several fractions of the SOM, that have specific C dynamics: soil C and N mineralization that arise during 3 years at cultivation of various cropping systems is more closely related to the amount of these fractions than to the amount of total C. For all cropping systems, a general relationship exists between soil respiration and the amounts of C present in the coarser SOM fractions above 50 µm (Loiseau *et al.*, 1996). After cultivation of a temporary ley, the mean yearly loss of C during 3 years increased from 2.5 C ha^{-1} y^{-1} (control grassland, non-fertilized) to 2.9 with slurry (100 kg N ha^{-1} y^{-1}) and to 2.8 with mineral N (300 kg N ha^{-1} y^{-1}) previously applied to the grass crop.

Three main SOM compartments account for the dynamics of N mineralization after grassland destruction. The basal, long-term, N mineralization is related to the loamy particle size fraction with a long residence time, whose OM is aggregated with the minerals (AOM). The major part of the soil N that can be mineralized in the first few years after cultivation is related to the extractable SOM fraction (EOM). This fraction, that can be extracted by salts or hot water (EOM) has a medium residence time. The short-term mineralization after grassland destruction is also due to plant residues which compose the particulate organic matter (POM). Net N mineralization from this SOM fraction disappear after 2 years and depends both on the amount and on the C:N ratio of the POM (Assman *et al.*, 2001).

In a long-term experiment (20 years), Loiseau *et al.* (1992) observed that both mineral and organic N fertilizer 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} y^{-1}. But no further soil C accumulation occurred for harvests from 11 to 14 t DM ha^{-1} y^{-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 was hypothesized 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 fertilizer rates.

Characteristics of SOM compartments under grassland

a. Root residues

Roots are particularly present in grassland systems. It is recognized to be an important factor of soil quality when the pasture is settled (favorable conditions for micro-organisms in the rhizosphere, building of water-stable aggregates due to exudated polysaccharides, …). This important root biomass should also play a major role after ploughing. Several recent works show that roots have to be studied seperately from other fresh organic matter. By labeling techniques, Puget & Drinkwater (2001) and Gale *et al.* (2000) found C in soil due to root material in higher proportions than predicted from the root/shoot ratio of the fresh inputs. In addition, Abiven *et al.* (2002) observed C mineralization for roots to be significantly lower in comparison with the aerial organ tissues for several different plant species. This suggests that soil organic matter coming from roots: (i) would be found in important proportions in the soil and (ii) has a particular dynamic, which would deeply affect physical, chemical and biological characteristics of the soil during the months following resowing.

b. Granulometric SOM Compartments

Specific soil OM compartments increase in grassland soils, whereas some others remain constant. 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-metabolized by microbial biomass, some of them being physically protected in aggregates; 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 the POM as substrates (Alvarez *et al.*, 1998; Assman *et al.*, 2001).

N availability seems to regulate the pathways according which the OM input evolves in the soil in temporary grasslands: (i) 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; (ii) microbial metabolites accumulate in EOM under low growth limitation by N and a balanced C:N ratio of the organic input (mixed swards); (iii) stable organic matter is subject to a fast turnover in highly fertilized grass swards, where carbon availability is the limiting factor for microbial activity. Therefore, 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 metabolization of the OM input, growth efficiency and turnover of the microbial biomass).

2.4.4 Effects of grassland management on C dynamics

The rate of C accumulation in grassland soils depends on the level of N input by fertilizer, slurry and biological fixation, and the grassland management. However, due to lack of data, these effects are poorly quantified (Table 6).

Table 6. Soil C storage according to changes in agricultural practices in fodder crops and grasslands (INRA expertise).

Grassland management	Annual fluxes for C storage during 20 years (t C ha^{-1} y^{-1})
Rational fertilization of intensive 1-2 years pure grass	0.3
Rational use and increase of life duration in intensive grasslands	0.1 to 0.5
From temporary to permanent pastures (same N level)	0.3 to 0.4
From poor permanent to temporary pastures (increasing N level)	0.1 to 0.2
From poor permanent to temporary pastures (same N level)	-0.1 to –0.2
Increasing intensification in poor permanent grasslands	0.2
Intensification of mountain swards	-0.9 to –1.1

2.4.5 Lack of research

C storage and mineralization stay an important research topic, whatever the cropping system is. However, particularities of grassland soils put the stress on the need of knowledge for some questions.

One important point is to establish more relations between the short-term and the long-term processes. There seem to be a certain lack of theoretical models that explain the integration on 'new' organic matter in the SOM pool, as well as the decay of the 'old' SOM, according to different factors. The consequences of this point is important when organic matter accumulates, but also when there are strong changes, f.i. caused by resowing. No relation has yet been established between fresh organic matter transformations and the setting up of stable organo-mineral complexes. The more advanced models distinguish several SOM compartments of specific attributes (quality, C:N ratio, time constants). The first, purely theoretical, models were only validated on the output fluxes or on the total soil C and N. A real comprehensive knowledge, as well as the setting up of precise soil indicators, would imply to validate the models on measured values of several SOM compartments. Theoretical compartments must be identified to measurable SOM fractions. Although significant results have been obtained from SOM fractionation methods, no real agreement exists in literature for such measurements. Moreover, much OM transformation in the soil seems to be continuous and a model of continuum would be preferable to discrete fractionations, which are sensible to the fractionation method. Finally, most of the models remain additive and, despite some hypothesis and laboratory results, little is known on the interactions between these compartments in field conditions.

Several factors, underlying grassland management, that influence the transformation of the OM input have been identified. One first group concerns the litter amount and quality. Firstly, the litter amounts are more difficult to measure in grassland than in annual crops: the measurement of root phytomass should be completed by that of its residence time. Secondly, a lack of knowledge concerns the components of 'litter quality'. This concept should be considered not only in terms of C:N ratio, but also in terms of chemical composition, in order to approach the concept of fermentescibility. Thirdly, major attention should be brought to the so-called 'detritus-sphere' in grasslands. The location of the 'new' SOM could have important repercussions on C and N dynamics, but also on structural stability, etc. This aspect would concern root morphology and architecture, which both condition the contact between the 'detritus-sphere' and its mineral, as well as microbial environment.

Another group of factors, that conditions OM transformation in the soil concerns the condition that prevail during *in situ* litter incubation. Laboratory tests, that have been used extensively for annual crops on arable land, should be used carefully for grassland application, because soil perturbation may induce artificial changes, as compared with reality. Especially, soil incubation with soil perturbation may simulate the C and N fluxes after grassland destruction, but not during grass cultivation. A first component of soil condition is the role of nutrient availability, especially N. A second one is the role of the living roots: (i) for N uptake and competition with microbial N immobilization; (ii) for exudation, which is likely to interact with other OM substrates for microbial activity and (iii) for soil prospection by the rhizosphere and interaction with the 'detritus-sphere'.

All these factors act on the OM transformations in soil through the microbial activity. Therefore more studies should focus on the structure of the microbial community and on the microbial functions, that concern the C and N fluxes: microbial growth efficiency would help explaining the yield of OM transformation; the microbial nitrification and denitrification potential, to explain the mineral N status and fate.

Among factors of OM transformations that directly depend on farmer practices in grasslands, is the management of C coming from cattle excreta and co-products (compost, manure). Those fresh organic matter types have very different characteristics compared to plant residues. The inputs of such products is well documented on nitrogen, but references on C are still rare. Among the output of OM transformations, a gap of knowledge from the point of view of C sequestration concerns the evaluation of the C storage potential in temporary grasslands. Previous studies did not permit accurate C budgets to be determined. This point would have to be developed rapidly, according to the environmental policy needs.

2.5 Conclusion

Soil quality (or qualities) is a topic of main interest in grasslands and ley-arable rotations for both agricultural and environmental cares. One key-point is OM, whose study in grassland soils is less advanced than in arable soils, partly because they previously offered less important issues. Such studies applied to grasslands may be more difficult, accounting for the diversity of OM inputs on a perennial, potentially plurispecific and diverse vegetation.

A lot of works are in progress to characterize SOM (amounts, quality, stability …) and to understand its contribution to both physical, chemical and biological quality of soil. Few references were related in this paper on biodiversity, this topic being mostly studied through ecological research on aerial components of grasslands: phytosociology of plant communities, genetic diversity, dynamics of plant populations, insects and mesofauna. In intensive ley-arable rotations, soil biodiversity will certainly become more important in future research. The concepts of functional ecology in studying biodiversity, including producers, decomposers and herbivores, seems to be the more relevant approach for application to grassland ecosystems.

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3. Organic C and N stocks and their long-term changes in sandy soils of North Germany

G. Springob[1] & H. Kirchmann[2]

[1] University of Hannover, Institute of Soil Science, Herrenhaeuser Strasse 2, 30419 Hannover, Germany, GuentherSpringob@aol.com

[2] Swedish University of Agricultural Sciences, Department of Soil Sciences, Box 7014, 750 07 Uppsala, Sweden

3.1 Introduction

This paper summarizes some of the results discussed in a series of earlier publications on the issue of organic matter (OM) storage and dynamics in sandy soils under moderate climate (Springob *et al.*, 2001, Springob & Kirchmann, 2002, 2003). Aims behind these studies were to quantify C and N stocks of old arable sites and of former grassland soils (Ap horizons) and to identify variables and indicators determining the probable future changes of OM stocks. Currently, the focus of interest is shifting towards recent grasslands in groundwater protection areas with respect to analytically predicting their N release potential before converting them (or not) into arable land.

Historically, a large proportion of current NW German arable soils was used as grassland, mostly under relatively moist conditions which generated huge organic C and N stocks. These soils were ploughed up after lowering the groundwater table by agricultural drainage, deepening of rivers, and frequently also by recovery of water by water-works.

In our main study area (Fuhrberg well fields, catchment and water protection area of 300 km^2 north of Hannover), grassland conversion on a larger acreage started at the end of the 50es, with highest intensities in the 70es and early 80es. These 'classical' conversions referred to sites which had been grassland 'ever since', meaning at least for about two centuries. We concluded this from a number of historical maps, the oldest one being the 'Kurhannoversche Landesaufnahme' from about 1780 (NLFB, 2000). Nonetheless, the recent grassland frequently has some kind of mixed history, involving phases of arable use, maybe even of woodland or heathland. But even recent grassland sites which earlier had been cultivated for a number of years, today show C and N dynamics still significantly, often dominantly determined by the long-term historical impacts, meaning long-lasting grassland and moisture. They still have fairly high C and N stocks mineralizing when being ploughed. In the past, the decline of OM stocks led to serious contamination problems with nitrate (seepage water) and sulfate (well waters) in the study area (Duijnisveld *et al.*, 1989; Strebel *et al.*, 1988, 1989; Frind *et al.*, 1991).

The following findings refer to

- OM stocks and qualities which determine the C and N mineralization potential
- reference values (probable final steady state levels) as obtained from old arable land
- the question of how long it takes to reach a new equilibrium when grassland is taken under cultivation and
- to climatic impacts on the steady state C and N levels under arable conditions.

Preliminary data on N stocks of recent grassland is also presented.

3.2 Material and Methods

Soils and methods are well described in Springob *et al.* (2001) and Springob & Kirchmann, (2002, 2003). C_{org} and total N were determined by a LECO C-N-S system. OM in Figure 4 is C_{org} times 1.72.

3.3 Results and discussion

NW German sandy soils have fairly high C_{org} levels, even at old arable sites

A common theory is that sands, if not extremely moist, do not accumulate OM due to the missing process of OM bounding by clay and other small mineral particles. E.g., in the concept of Körschens *et al.* (1998), the optimal C level of arable soils (Ap horizon) is derived from the content of clay plus fine silt. The concept assumes that any soil contains 'inert' C_{org} in amounts depending on its texture. The fraction is determined as the C level in zero plots of long-term field experiments. Above this basic level, a certain amount of OM should exist to secure soil fertility, and this optimal content is assumed to be independent from texture (Figure 1). There has been developed a number of further concepts relating OM stability to texture, e.g. the 'texture preserved C' of Hassink & Whitmore (1997) or the stable C of the Rothamsted carbon model (Jenkinson, 1990). However, Figure 1 clearly shows that our sands have very high C levels, and this is not only true for former grassland but also for very old arable land, even if they have less than 5% clay. The reason for the high C levels is, that much of the OM in old arable soils is extremely stable (refractory OM), mainly due to specific factors of historical land-use and climate (Springob & Kirchmann, 2002).

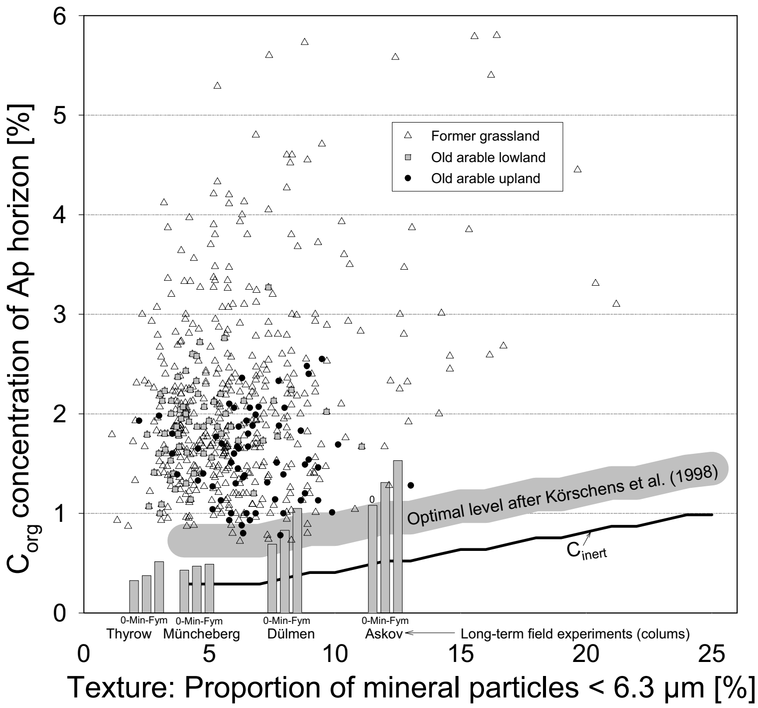

Figure 1. *C_{org} levels in recent Ap horizons (about 0-28 cm depth, mean density 1.4 g cm^{-3}). Each symbol represents one field. Also included are columns representing plots of long-term field experiments as reference C levels, their x positions just roughly indicating their texture. 0: unfertilized. Min: Mineral fertilizer. Fym: Farmyard manure. The long-term data are from own measurements of the author but similar data as well as background information can be taken from Christensen et al. (1994), Ellmer et al. (2000), Ellerbrock et al. (1999a,b), Körschens et al. (1996, 1998).*

It may take 50 to 80 years to reach a new (lower) steady state of OM after converting grassland into arable land

The chrono-sequence (Figure 2) showed that it will take a number of decades until the lower C levels of the arable soils of today would be reached by former grassland – if the boundary conditions remain constant on the arable land. If we do additionally consider that the old arable land, which provided the reference level in Figure 2, contains stable OM inherited from historical times (and that climate is warming up), than today's old arable land may even overestimate the final equilibrium C level. This would mean that C losses could be stronger than suggested in Figure 2, and that the process of net C and N mineralization may last even longer.

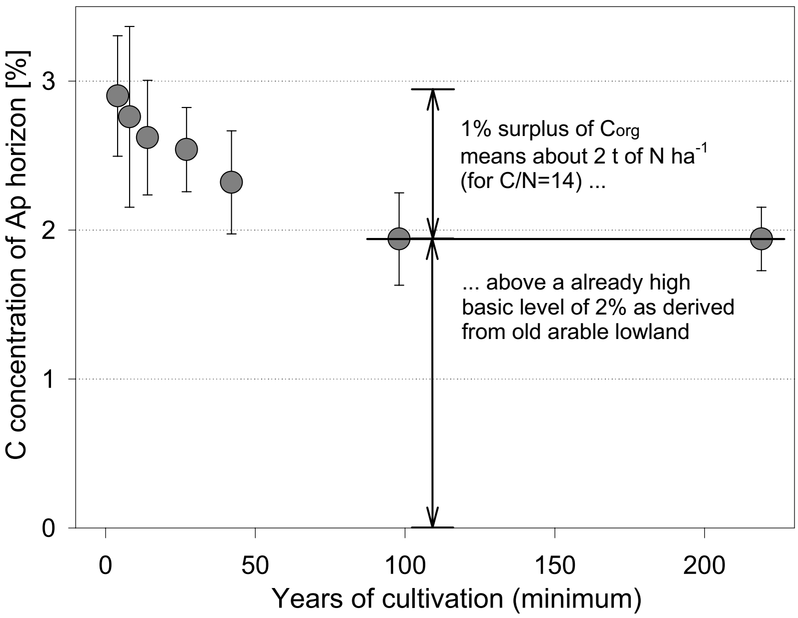

Figure 2. Average C contents of the Ap horizons of now cultivated former grassland (ploughed annually) and of old arable land as the reference basis (line). Only lowlands of the Fuhrberg catchments were included (for details see Springob et al., 2001).

Climate has considerable influence on reference C levels of old arable land

This is illustrated in Figure 3 in which old arable soils from a number of sites along a Southwest-Northeast climo-sequence were analyzed. The C levels increased by a factor of more than 3 with increasing precipitation. Reasons are (dominantly) an increasing proportion of that specific stable OM of Northwestern sandy soils and (less important) an increasing annual C input under a moister climate. Thus, the estimates for final steady state levels of OM contents must be determined regionally. Climate is much more important than texture.

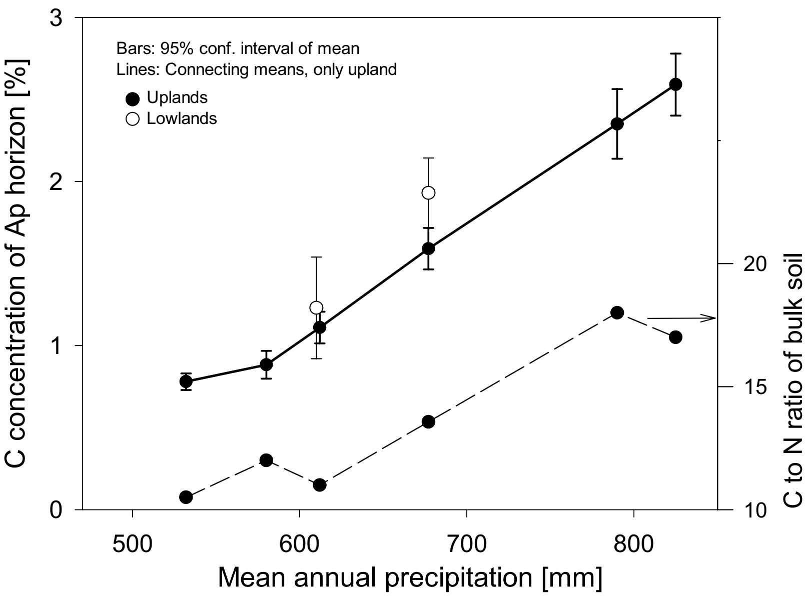

Figure 3. *Mean regional C contents of old arable land along a climo-sequence from the dry, more continental Southeastern part to the moister Northwestern part of the North German Pleistocene plain.*

In sandy arable soils, the C to N ratio of the bulk soil indicates N release from non-fresh soil organic matter

The N release has been determined in aerobic incubation experiments at 35° C over 250 days (Springob & Kirchmann, 2003). The resulting cumulative curves could be split into N released from fresh OM (N_{fast}, pool and rate coefficient, exponential) and from non-fresh OM – the whole remaining (only rates, referred to as N_{slow} rates). The N_{slow} release rates per gram of OM were closely correlated with C to N ratio (Figure 4). The correlation between N_{slow} release rates per gram of soil and total N was much weaker (not shown). The bulk soil C to N ratio, thus, seems to be a promising indicator of the N releasing potential of sandy soils. However, it is still unclear whether this also holds true if recent grassland soil material is incubated. A series of experiments on this question is recently being launched in April 2003.

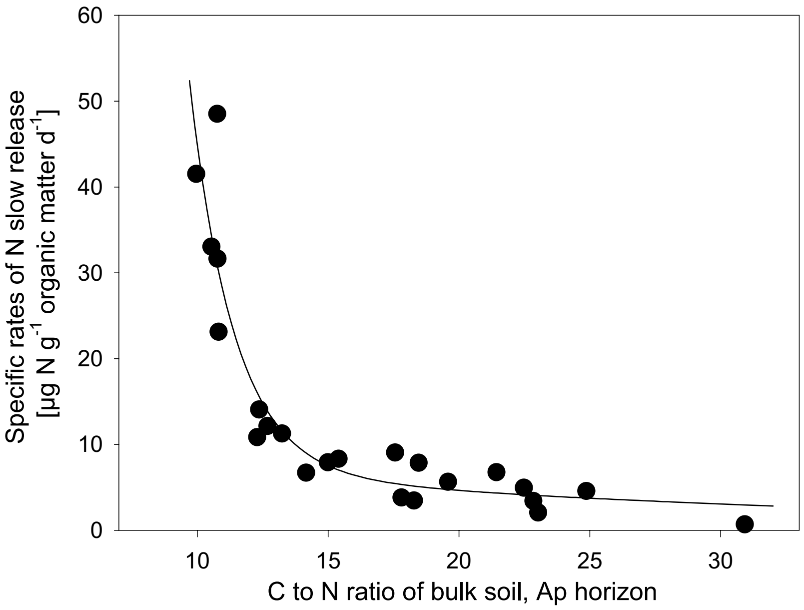

Figure 4. *Relationship between the specific rates of N release from non-fresh soil organic matter (OM instead of dry soil as a basis) and bulk soil C to N ratios. The soils span a wide range of cultivation history and soil genesis, and they were collected at different locations throughout the North German plain, but: all are Pleistocene sands with clay contents < 6%.*

The N stocks in the OM of recent grassland of the Fuhrberg catchment range from 4 to 14 tons ha^{-1} in the Ah horizons

The investigations on current grassland and its potential to release N when being taken under cultivation (still a severe problem in groundwater catchments nowadays when most farmers do not any longer need grassland), have just started. The N stocks of the first 46 studied sites are shown in Figure 5. They are plotted against the C concentrations of the Ah horizons to illustrate the range of both variables. The depth of most Ah horizons was close to the average Ap depth of the arable sites (28.5 cm) because nearly any grassland site has been ploughed at least once in its history to resow the grass. Much deeper Ah horizons were only observed in extremely moist sites. Such sites were not included in Fig. 5. Surprisingly, the bulk density of these grasslands, measured at about 15 cm below surface, was not, as expected, lower than in arable soils on similar parent materials. It seemed to be slightly higher, but data are still too scarce to elucidate this point.

To evaluate the N stocks of grassland quantitatively, Figure 5 also shows the average total N stock of old arable lowland which is about 4.6 t ha^{-1}. This comparison clearly shows that recent grassland still carries a considerable potential to release N – probably some tons per hectare. Thus huge N losses after grassland conversion are not merely a historical process, but really can be a recent problem.

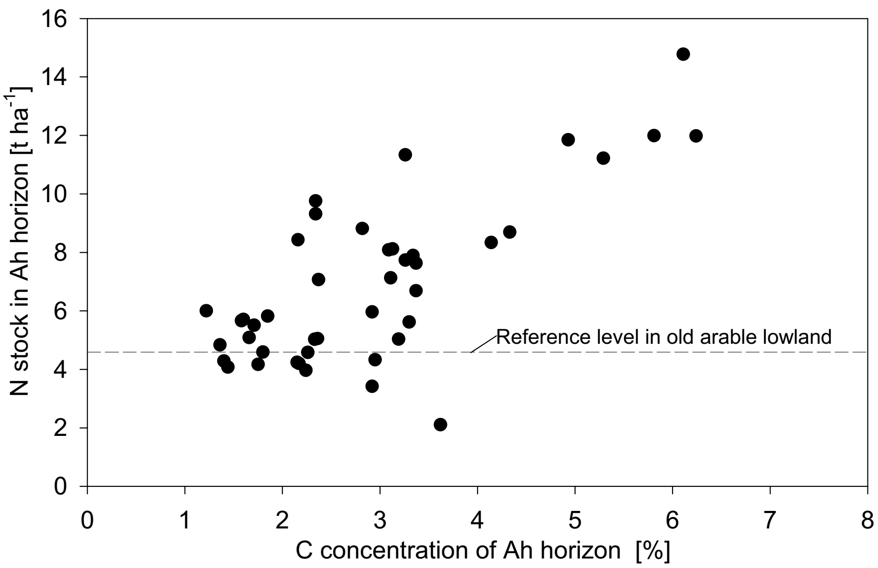

Figure 5. *Recent grassland, 46 fields: N stocks of the Ah horizon (around 30 cm depth, sometimes less) vs C concentration of the Ah horizon (C as an average over the complete depth). Bulk density and depth of Ah horizon for calculating N stocks are measured values (11 locations on each field, averaged). The range of bulk densities was about the same as in arable soil, with a tendency to slightly higher values under grassland.*

3.4 Conclusions and work in progress

Historical grassland, now cultivated since many years, still has impact on today's C and N turnover. The formerly accumulated C and N stocks are still in the process of net-mineralization, even decades after the conversion. The remaining, *recent* grassland (just 46 sites were analyzed until now) also has a huge potential of releasing N, probably not much less than historical grassland. In groundwater catchments, such conversion should be avoided if possible or, at least, should be restricted to sites with lower N release potential. Current work concentrates on the question of how to predict the N release potential *prior* to conversion. Required are more precise indicators than just total N levels. OM quality has to be included. Laboratorium incubation experiments will show whether the C to N ratio is a suitable indicator in this context, as it was shown to be for arable land. Further work focuses on refining a C-N budget model (*CSaNd*). As input, the current version just needs parameters for total C and N levels, annual C input and a coefficient of decay. Output of the model comprises the prediction of future C levels in arable land and the associated N losses when the OM levels decline (for sands only). However, the model still needs to be modified for the very initial years after grassland conversion, i.e. the underlying terms and parameters must be adopted to (or, at least, must be tested for) standing grassland.

3.5 Literature

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Theme 3.

Crop and animal performance

4. Crop and animal performance in grass-to-grass resowing

J.G. Conijn

Plant Research International B.V., P.O. Box 16, 6700 AA Wageningen, the Netherlands

4.1 Introduction

Maintaining or increasing grassland productivity is one of the key motives for farmers to resow their grasslands. Grassland productivity on farms may decline gradually from year to year or drop suddenly to a lower level. Various causes can be responsible for this decrease, such as unfavourable soil conditions (f.i. compaction), weather damage to the sward (drought or frost) and invasion of undesired plant species. At some point in time, it may be profitable to plough and resow the sward, as in most situations a higher productivity is expected in the years after resowing relative to the years before resowing. The increase in productivity must be substantial, because it should at least compensate for the loss in grassland productivity in the year of resowing, which occurs if the grass sward is ploughed prior to resowing. Figure 1 illustrates the development in grassland productivity, as described above, including the assumption that the 'final' production level after resowing is higher than before (see also section 9.1). It is presented here as an hypothesis that should be tested with experimental data.

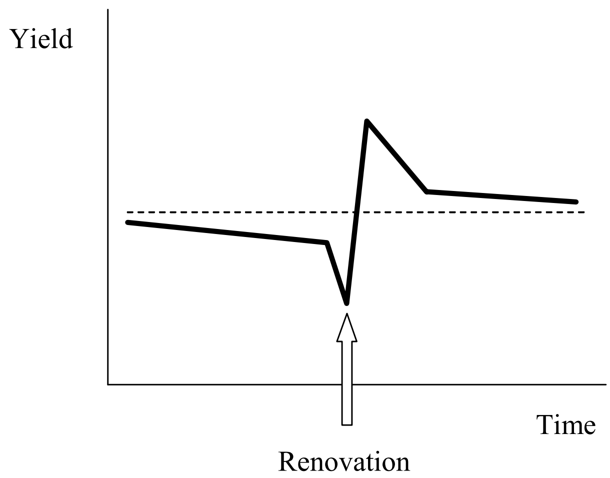

Figure 1. Hypothesised yield development of grassland in time.

In this chapter the hypothesis of Figure 1 is split into three main questions, which can be answered seperately:
1. To what extent does the yield decrease with grassland ageing takes place?
2. Does the yield improvement outweigh the yield loss in the year of ploughing?
3. Which yield variable is important for the farmer (grass dry matter, protein, animal intake/production, etc.)?

Data from the Wageningen workshop, as published in Conijn *et al.* (2002), have been used for answering these questions and the results are described in section 4.2.

4.2 Results and discussion

4.2.1 Decreasing yields with increasing age?

The first question for testing the hypothesis of section 4.1 reads:
To what extent does the yield decrease with grassland ageing takes place?

Table 1 contains the results based on the data found in the proceedings of the Wageningen workshop. Yields have been expressed in relative units (%) in order to compare the original data from different countries.

Table 1. Relative grass yields (%) during subsequent years after resowing.

Country	DK[1]		B[2]		NL/UK[3]		IRL[4]	
	Cut	Grazed	Grass	Gclov	DM	N	4%	15%
Year 0			92	93	80	80		
1	263	110	88	88	125	115	}	}
2	229	107	91	72	103	98	} 135	} 102
3	176	100	92	105	103	98	}	}
4			100	101	103	98	100 ?	
5	100		100	100	103	98		
6								
100 % =	3.8 [5]	8.1 [5]	11.3 [5]	9.8 [5]	8.4 [5]	280 [6]	10.1 [5]	13.5 [5]
Sowing	Spring		Autumn		Spring		?	

Note: Year 0 is the year in which the grass is resown (either in autumn or in spring).

1 *Yields of temporary grass swards in subsequent years. Cut: average values for a fertilization level of 300 kg N ha^{-1} y^{-1} with/without irrigation; Grazed: values have been estimated based on calculated intake (Soegaard et al., 2002).*

2 *Yields of temporary grass swards of different ages sown in subsequent years. Yields were determined by cutting strips, swards were grazed rotationally. Grass is grass dry matter and Gclov is dry matter of a grass/clover mixture (Nevens et al., 2002).*

3 *Estimated dry matter (DM) and nitrogen (N) yields of grass swards of different age. Production in year 0 is assumed to be 20% lower and the dry matter production level in year 2 and later is assumed to be 3% higher due to genetic improvements of the newly seeded grass variety (Schils et al., 2002). Data from the UK (Hopkins et al., 1990; 1995) have been used to estimate the values in year 1.*

4 *Yields of old swards compared to reseeded swards, measured by taking three or four cuttings per year. Two situations: old sward containing only 4% and 15% of Lolium perenne respectively (Humpreys & Casey, 2002).*

5 *Unit is ton dry matter ha^{-1} y^{-1}.*

6 *Unit is kg N ha^{-1} y^{-1}.*

Figure 1 gives an illustration of the dry matter data of Table 1.

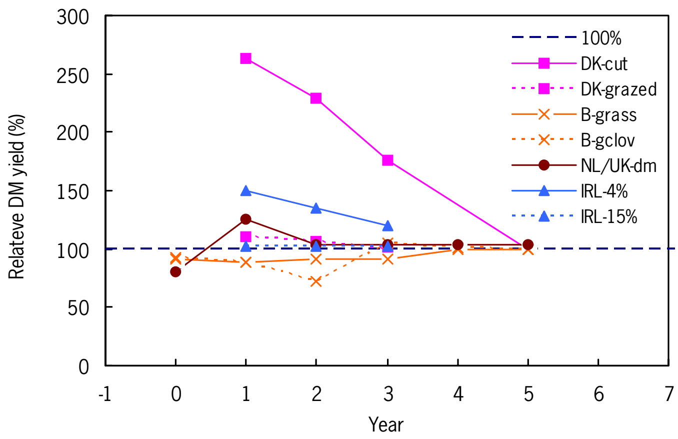

Figure 1. Relative grass dry matter yield as function of number of years after resowing. Based on data from Table 1.

Only two out of seven datasets show a substantial decline in grassland productivity over the years (DK-cut and IRL-4%). The others do not show any substantial decrease over the years. Some of them even had lower yields for some years shortly after resowing (Belgium data). The slope of the DK-cut data is extremely negative compared to the others and also its production level at 100% is an outlier (after 5 years: 3.7 t ha^{-1} y^{-1}). This situation clearly does not represent a permanent grassland, but a short-term, fast-degrading ley for which plant species varieties may have been selected that do not seem to persist very well under the prevailing growing conditions in Denmark.

Other relevant data from the Wageningen workshop concerns:

- In Belgium an experiment comparing permanent grassland with three-year temporary leys during 31 years resulted in almost equal feed energy yields from both grassland types at equal fertiliser N input (75.1 GJ NEL ha^{-1} for permanent and 73.3 GJ NEL ha^{-1} for temporary grassland (Nevens *et al.*, 2002).
- In northern Germany a proportion of 77% of the grassland fields is older than 10 years and circa 50% is older that 30 years in convential farming systems (Taube *et al.*, 2002).

The long-term experiment in Belgium does not seem to support the hypothesis of lower yields on old grassland, as the permanent grassland produced even slightly more than the young grassland which had an average age of only 2 years. But this conclusion can be debated because it has been derived from a comparison of grassland fields in a rotation system with grassland fields in a permanent grassland situation. Probably, the amount of soil organic N will be different in the two situations with a higher level in the permanent grassland fields, due to the higher N inputs accumulated over the years. It is likely that in the temporary leys total N availability (from external inputs + soil supply) was lower due to an assumed lower N mineralization correlated with the lower organic N content in the soil. This may have influenced the ley production level. Whatever the case may be, the experiment in Belgium is not just about comparing between old and young grassland, but also between permanent grass and temporary grass interrupted by arable cropping.

The data on grassland age of northern Germany clearly shows that a large proportion of the grassland fields is not renovated frequently and may therefore suggest that the degradation with ageing is not very substantial in this part of Europe. It should be noted however that the intensity of grassland use partly determines the need for renovation, because (i) in some cases intensive use of grassland may be directly responsible for sward degradation and (ii) farms with a high stocking rate generally need a high grass production level which is assumed to be more easily obtained from younger swards. So, the the situation of grassland use in northern Germany may differ from other regions in Europe, such as the Netherlands or Belgium, where grassland renovation is practised more often. Indeed, the intensity of fertiliser use in northern Germany seems moderate as compared to f.i. the Netherlands, as 67% of the grassland fields received less than 221 kg N ha^{-1} y^{-1}. Unfortunately, the data of grassland age in Taube *et al.*, (2002) could not be related directly to fertiliser intensity, nor could they be compared with corresponding experimental data from other regions in Northwest Europe.

4.2.2 Production increase versus production loss

The second question for testing the hypothesis of section 4.1 reads:
Does the yield improvement outweigh the yield loss in the year of ploughing?

Based on the data from Table 1, it may be concluded that in general the production increase is more or less equal to the production loss if permanent grassland is renovated. The total gain in dry matter production seems therefore negligible and is in some cases even negative (see data from Belgium). The experimental results are surprisingly in view of the frequent grassland renovation practice at dairy farms (f.i. in the Netherlands). A number of reasons may be responsible for this observation and some of them are pointed out below.

- Grassland renovation at farms occurs more often than is needed, maybe partly due to the difficulties in making a realistic cost/benefit analysis in terms of productivity of resowing a single field on a farm.
- In some experiments the new grassland has been compared to old grassland that is still in 'a good shape' and therefore produced as good as the reseeded swards.
- Substantial difference between young and old grassland can only be found in some years, f.i. during dry periods in summer. This might be explained by better rooting characteristics of the young swards which is only beneficial if soil moisture conditions become limiting for the older swards during the growing season. In other years, with good growing conditions, the difference is relatively small and this hampers a clear-cut conclusion from the data.

4.2.3 Which yield variable matters?

The disappointing results when looking at the absence of the assumed dry matter advantage of grassland renovation in combination with the observed practice of frequent resowing at dairy farms, brings up the third question:
Which yield variable is important for the farmer (grass dry matter, protein, animal intake/production, etc.)?

In other words, dry matter yield as determined in many experiments (mostly by cutting: gross production) may not be the right variable to measure when studying the pro's and con's of grassland renovation. In general, two other variables seem more important than gross dry matter production, i.e. (i) net intake by animals and (ii) nutritive value of the grass. In Conijn *et al.*, 2002 the following information could be found on this issue:

- The Netherlands suggested lower grazing losses and thus higher animal intake, but experimental data are lacking to support this.
- Ireland found in general a higher nutritive value and silage quality for *Lolium perenne* compared to other plant species.
- But Belgium determined equal feed energy yields from old and young grassland (see 4.2.1) and
- the United Kingdom reported similar animal production rates after grazing on permanent and reseeded grass swards (Hatch *et al.*, 2002).

So, evidence for these alternative variables being substantially improved by grassland renovation seems conflicting and is therefore not unambiguously supporting the hypothesis.

4.3 Conclusions

Concluding

- The hypothesis can not be accepted due to lack of experimental evidence, based on the data as published in the proceedings of the Wageningen workshop (Conijn *et al.*, 2002).
- However, this may be caused by measuring the wrong variable, i.e. the gross dry matter production. More effort is needed to look at other productivity measures such as animal intake, digestibility, nutritive value and/or animal production.

- In line with the above, efforts should be concentrated more on the whole cylce of fertiliser use – grass production – animal intake – production of milk/meat and animal manure that can be used as fertiliser again, in a farm situation.

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5. Crop performance in grass-arable crop rotations

K. Søegaard

Danish Institute of Agricultural Sciences, Research Centre Foulum, P.O. Box 50, DK-8830 Tjele

5.1 Introduction

The grass-arable rotation system has originally its background in the positive residual effects of the grass on the following arable crops concerning fertility, diseases and weeds. Newly sown swards are on the other hand more vulnerable to pests and diseases than established grasslands. The yield in the grass-phase compared to longer lasting grasslands is assumed to be higher, just as the net gain of the whole crop rotation compared with the crops in monoculture. The yield of the arable crop after ploughing the grass are normally reported higher than in monoculture, especially at low fertilizer level. However, there are different reports regarding the benefit on the yield of the arable crop could be replaced by N-fertilizer. Experiments in Rothamsted with different arable crops showed that the benefit could be replaced, except for potatoes (Hatch et al., 2002). The same was found in Gent (Belgium) with silage maize (Nevens & Reheul, 2001), whereas in cereals at Foulum (Denmark) the benefits could not be replaced (Eriksen, 2001).

With the decreasing use of fertilizers and pesticides the benefits of the grass-arable rotation system becomes more topical. However, it is a challenge to optimise the positive residual effects for the whole grass-arable system. The grass-phase typically last for 2-4 years, and the length of this phase might highly influence the residual effects of the soil-N accumulation. For maximising the net gain of the grass-phase, a high level of herbage production and quality is desirable, especially if a constant level could be maintained. In this paper the herbage production and quality during the grass-phase is discussed.

5.2 Herbage production

The annual dry matter yield decreases in most cases over the years with the highest yield in the first harvest year and often the decrease from the first to the second year is reported higher than between the other years. However, there is a great variation in reported results from no decrease from first to third harvest year (Charles, 1973; Baars, 2002) to a decrease of 25% (Hopkins *et al.*, 1990). But there are also examples with a lower yield in the first years compared to well-established (6 years) grasslands (Nevens *et al.*, 2002). Under cutting conditions the decrease seems especially to be situated in spring (Table 1) at the time when the herbage quality is highest. The criteria for ploughing the grassland in the Northwest Europe seem not to be very specific. Existing criteria concern primarily the botanical composition. In Belgium it is recommended that couch grass does not present more than 15%. In the Netherlands it is recommended to have more than 50% perennial ryegrass and less than 10% couch grass, and in Ireland the corresponding limits are 40% of perennial ryegrass and 30% of undesirable species (in: Conijn *et al.*, 2002). In the grass-arable system, however, the grass-phase will often last too short to reach these limits, and the criteria for ploughing the grassland seems more to be a question of the rotation schedule.

Table 1. Dry matter yield (kg DM ha^{-1}) in grass/clover without N-fertilisation. Results from three pilot farms. Comparison of first and second year ley (2000-2002). Results from the same year are compared, not from the same field.

Cut	Year 1	Year 2	Diff.	$LSD_{0.05}$
1.	3,231	2,560	671	224
2.	1,752	1,866	-114	ns
3.	1,770	1,789	- 19	ns
4.	890	888	2	ns
Total	7,535	6,992		304

Søegaard, 2004

The herbage yield over the years has, as mentioned before, not a certain trend. Maintaining a high yield level during the grass-phase will to some extent depend on the management factors, but climatic conditions will also contribute to the decrease. In cold climates winter damage is pointed out to be a main reason for yield decrease over the years (Lien *et al.*, 2003) and also drought stress during the growing season has an effect (Gregersen, 1980). Management has great influences on production rate, tiller density, etc. and therefore management decisions, such as N-fertilization and cutting/grazing regime, could be assumed to affect the persistence. However, there seems to be a lack of knowledge concerning this topic.

Nitrogen is a management factor, which highly influences the production profile and yield. The grass-arable system is characterized by a build-up of soil-N during the grass-phase, especially under grazing, and a decrease of soil-N during the arable phase. Although a greater yield-response to N (kg dry matter per kg N applied) at the beginning of the grass-phase might be expected, this has not been confirmed unambiguously. Nevens & Reheul (2003) found, that grass swards with a low clover content gave the highest response in the second year, whereas for grass-clover with a high clover content the highest response was in the first year (Frame & Boyd, 1984). Schils (2002) found in some cases a constant response and in other cases a decrease over the years. Other nutrients could have a contributory effect for the variable results, as Baars (2002) found that P and K level should be sufficient for a yield increase.

At a high N-level it is well known that the content of clover decreases strongly as well as the tiller density of grass. The yield decrease over the years could therefore be expected to be higher at high N-levels. This is supported by Gregersen (1980) in pure grass, who found, that the yield decrease from the first year to the third year under cutting conditions was 10, 17 and 21 % at a N-level of 100, 300 and 450 N ha^{-1} y^{-1}.

In grass/cover swards strategic N-fertilization has been examined very well, especially under cutting conditions (e.g. Frame & Newbould, 1986). At strategic N-fertilization N is used to improve the herbage production in spring and/or autumn, when the growth of white clover is low due to low temperatures. The growth profile can be manipulated as well as the clover content and the density of clover growing points. At spring N-application the white clover content increased during the growing season, and the persistence could therefore be expected to increase compared to a more even application of N. However, this topic, i.e. the residual effects of strategic N-fertilization on the following year, has not been examined.

The grazing/cutting management seems also to influence the persistence. Under grazing there is a higher N-surplus than under cutting due to the N-excretion from the grazing animals, which can affect the production during both the grass-phase and the following arable crops. Hassink (1992) found a higher N-mineralization under grazing than under cutting, which can be one of the reasons for a lower N-response under grazing than under cutting (Lantinga *et al.*, 1999). In spring in the second year, the yield of the first cut was 28 % higher, where the grass/clover sward in the first year was grazed by dairy cows compared with cutting in the first year. This increase could be due to the higher

N-mineralization and to a higher density of grass tillers (Søegaard, 2004). On the other hand, the herbage production can also be reduced by grazing, especially when grass/clover is grazed by sheep, and in such cases strategic rest periods can improve the sward (e.g. Gooding & Frame, 1997).

5.3 Herbage quality

In short lasting grassland, species and varieties with a high production rate and a high herbage quality are often chosen, and therefore a high herbage quality can be expected during the whole grass-phase. However, the botanical composition changes over the years, and by this the herbage quality also changes. There has been a great focus on studies with grass mixed with white clover, but the trend over the years has been reported very differently. However, in grass mixed with red clover, the clover content often decreases over the years (e.g. Frame *et al.*, 1972).

But the age of the sward might also affect herbage quality. This is indicated by Wilkins (2000), who measured a decrease in stem content of perennial ryegrass from the first to the second year. The build-up of soil-N during the grass-phase could also affect the herbage quality. In spring in the second year the content of crude protein in perennial ryegrass was higher than in the first year, 14.4 % compared with 12.0 %, whereas the content of crude protein in the rest of the growing season and in white clover was unaffected by the age of the sward (Søegaard, 2004). This effect can be due to the build-up of soil-N.

5.4 Conclusion

The trend of herbage production during the grass-phase is reported very differently, but management could influence the persistence. For the time being, however, there is a lack of knowledge concerning how the management could be used as an active factor to maintain the production level. In most reported experiments the different harvest years are from the same plot and not from the same year, and therefore the effect of sward age is difficult to examine because it interacts with different weather/climate conditions and harvest dates over the years. Concerning the effect of sward age on herbage quality, there also exists very little knowledge. Although, the quality is normally high in short lasting grasslands, there could still be an effect of age and of the build-up of soil-N, which changes the herbage quality over the years.

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6. Performance and N surplus of forage crop rotations

M. Wachendorf, K. Volkers, H. Trott & F. Taube

Institute of Crop Science and Plant Breeding, Grass and Forage Science/Organic Agriculture, Christian-Albrechts-University, Kiel, Germany

6.1 Introduction

From a previous experiment on permanent grassland (Taube and Wachendorf, 2001; Büchter *et al.*, 2003; Trott *et al.*, 2003; Wachendorf *et al.*, 2003), where NO_3 leaching losses were measured over a 4 year period, following conclusions can be drawn:

- Due to the high N return by grazing animals leaching losses in rotational grazing systems generally exceeded the EU limit for drinking water.
- Reducing the N fertilizer intensity and inclusion of one or two silage cuts in spring in a rotational grazing system reduced leaching losses. However, even in unfertilized mixed systems N_2-fixation by clover exceeded the amounts of N removed via animal products, resulting in leaching losses well above the EU limit.
- In terms of NO_3 leaching losses, the cutting-only system is the most advantageous treatment in this study.

From another field experiment with maize for silage (Volkers *et al.*, 2002), which tested the effects of mineral nitrogen fertilization, slurry application rate and the use of an understorey with perennial ryegrass on the nitrate leaching losses, it became obvious, that

- an increasing N supply with mineral fertilizer or slurry resulted in increased leaching losses, with fertilizer N showing greater effects than slurry N.
- a grass understorey sown at the end of May (BBCH-Code 12/13 of maize) significantly reduced the losses. At high levels of soil N content leaching losses were strongly reduced with a grass understorey, whereas no differences occurred at low levels.
- leaching losses were positively related to the N budget, which was calculated from the difference between N input (N from fertilizer and slurry) and N output (N removed with herbage mass). At a constant level of N surplus leaching losses were smaller when maize was grown with an understorey.

These results lead to the idea that, inclusion of the grassland as a short term ley in a crop rotation before a maize crop and following cereals may reduce overall NO_3 leaching losses through an efficient uptake of possible surpluses from the ley phase by the maize crop. On the other hand negative ecological effects of maize cultivated in mono-culture, like soil erosion or humus degradation, might also be reduced. To evaluate the potential of this strategy a field experiment was established in 1999 at the same site as the permanent grassland and maize trials. This paper reports first results from a three year period.

6.2 Material and Methods

The experiments took place on the experimental farm 'Karkendamm' (mean precipitation 802 mm; mean temperature 8.3°C; soil type: deep ploughed treposol; texture: sand with less than 5% clay; pH 5.6).

Permanent Grassland Experiment

The regarded management systems were pastures (rotational grazing), hay pasture I and hay pasture II (one and two cuts respectively plus aftermaths), cut swards for silage as well as simulated pastures. Within these treatments there were four mineral N fertilizer levels (0, 100, 200, 300 kg N ha^{-1}) as well as two slurry levels (0 and 20 m^3 slurry ha^{-1}). Grazing was performed with heifers. This paper presents data from 1997 to 2001.

Maize Experiment

The experiment implies three levels of cattle slurry (0, 20 and 40 m^3 ha^{-1}; average N content 2.9 kg N m^{-3}) and four levels of mineral N fertilizer (0, 50, 100 and 150 kg ha^{-1}) as ammonia nitrate. All plots received 30 kg phosphorus ha^{-1} by side dressing and a broadcast application of another 35 kg ha^{-1}. Potassium was applied to all variants corresponding to the highest level of cattle slurry application. This paper presents data from 1997 to 2001.

Crop Rotation Experiment

Basic Assumptions

The underlying data for adjusting stocking densities and amounts of slurry are deduced from a typical specialized dairy farm in northern Germany with an average stocking density of 1.8 LU ha^{-1} and 100 grazing days for cows and young stock. In such a scenario about 25 m^3 slurry ha^{-1} $year^{-1}$ would be available.

Crops

Clover/grass ley:	2 cuts + 2 grazings, last cut remains undisturbed on the field and is ploughed in before the sowing of maize (catch crop)
Silage maize:	Whole crop silage
Triticale:	Whole crop silage and grain respectively

The field experiment was conducted from 2000 to 2002. All crops are grown for one year. In each winter the soil is covered by a living crop. In the experiment every crop was grown in each of the three years. The given results are therefore means over three years.

N intensities

Three different scenarios of forage production have been established. For all scenarios the goal is to achieve a certain overall feed supply (roughages plus supplements) in order to fulfill a given milk quota in the corresponding farms:

high:	high forage production (average fertilizer N supply 150 kg N ha^{-1} + 25 m^3 slurry ha^{-1}), low supplementation
reduced:	reduced forage production (average fertilizer N supply 75 kg N ha^{-1} + 25 m^3 slurry ha^{-1}), medium supplementation
low:	low forage production (average fertilizer N supply 0 kg N ha^{-1} + 25 m^3 slurry ha^{-1}), high supplementation

Table 1. N supply by mineral fertilizer and slurry at various intensity levels in the crop rotation trial.

Crop	Mineral fertilizer (kg ha $^{-1}$)	Slurry-N# (kg ha $^{-1}$)	total-N (kg ha $^{-1}$)	Standard values* org.+ min. N (kg ha $^{-1}$)
	1. High N Intensity			
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
Ø N-input	**150**	**75**	**225**	**193**
	2. Reduced N Intensity			
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
Ø N-input	**75**	**75**	**150**	**193**
	3. Low N Intensity			
Hay pasture II	0	75	75	250
Maize silage	0	75	75	150
Triticale	0	75	75	180
Ø N-input	**0**	**75**	**75**	**193**

On average 3.1 kg total N m^{-3} slurry.
* *From administration.*

To take maximum advantage of the high N-use efficiency of maize, mineral N intensity within a treatment was lowest for maize. To increase the benefit from white clover, the grass ley received intermediate amounts of N. Assuming that maize takes up most of the available N from the grass ley, it was supposed that triticale needed the highest amounts of N to produce satisfactory yields. Details on the distribution of mineral N among the crops are shown in Table 1. In order to obtain an extended variation in N intensity in the trial, all intensity levels were conducted with and without the use of slurry.

N balances

N balances on a field level considered only external N sources and were calculated as follows:

N input

Mineral fertilizer N
+ slurry N
+ N biologically fixed by clover
+ deposition N

N output

N yield in harvestable biomass
- residual biomass N (grazed swards)
- excrement N (grazed swards)

N surplus = N input – N output

6.3 Results and Discussion

The goal was to compare the performance and N surplus of forage production in i) a crop rotation with grass ley, maize and triticale and ii) in a system with permanent grassland and maize in monoculture. For that purpose, the data of the crop rotation (below referred to as ‘crop rotation system’) were aggregated by calculating averages over the three crops, equivalent to an area of 33.3% of each crop. As for the alternative system (below referred to as ‘monoculture system’), it was assumed that 70% of the area is permanent grassland and 30% is used for maize.

It is important to note that such comparisons are confined to the field level, as the amount of slurry applied to the crops were constant in all treatments. As forage yields vary strongly among the treatments, this would result in variable slurry doses in consistent farming systems. Furthermore, the fact that the experiments were conducted in different years may cause some bias.

Net energy yield of the crop rotation system was superior to the monoculture system at all levels of N intensity (Figure 1A).This is due to various reasons: Firstly, clover contents in the grass ley were higher than in permanent grassland swards, resulting in higher N fixation rates and higher yields at low and moderate levels of fertilizer intensity. Secondly, maize in the rotation benefitted strongly from the N release by the soil after ploughing the ley. Thirdly, triticale produced high dry matter yields with medium energy contents. For the crop rotation system the slope of the regression line is linear over the whole range of N intensity, indicating that by the highest level of N intensity in the trial, the yield maximum of the production system was not achieved yet.

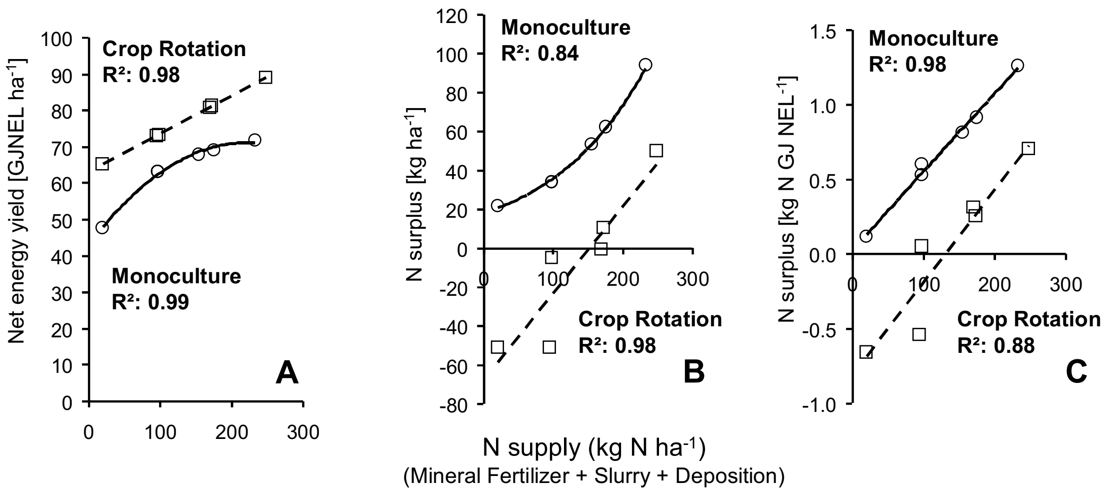

Figure 1. Net energy yield (A), nitrogen surplus per ha (B) and nitrogen surplus per GJ NEL (C) in forage production from monoculture and crop rotation system, respectively, as affected by nitrogen supply.

N surpluses per hectare were higher for the monoculture system at all levels of N intensity (Figure 1B). Although two cuts are taken in spring and much N is removed from the field, N surplus is still positive on the permanent grassland, which is due to the low N retention in animals grazing in the second half of the growing season. The higher N efficiency of the maize does not bring about much reduction in the overall surplus, as it represents only 30% of the farmed area. As a consequence of high surpluses per hectare and low energy yields, the N surplus per GJ NEL produced is much higher in the monoculture system at all levels of N intensity (Figure 1C).

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Theme 4.

Farm management and economics

7. Farm management and economics – grassland renovation

I.E. Hoving & H.C. de Boer

Animal Sciences Group, Wageningen UR, Applied Research, P.O. Box 2176, 8203 AD Lelystad, the Netherlands

7.1 Introduction

In this paper the economics of grassland reseeding are discussed. The economics of grassland reseeding is described by the following 5 topics:
1) Productivity after renovation,
2) motivations of dairy farmers in North West Europe to renew grassland,
3) criteria for the right moment for renovation,
4) reseeding methods and
5) the economic benefits.

The information is mainly derived from the proceedings of the first meeting of the EGF Working Group 'Grassland Resowing and Grass-arable Rotations' (Conijn *et al.*, 2002). Literature information on practical aspects of grassland renovation is scarce. However, such information is essential to carry out a good cost/benefit analysis. Probably, there is a tension between research results on the one hand, because they show limited effects of improved dry matter yields, and positive experiences of farmers on the other.

7.2 Productivity after renovation

Research results of the last decades often did not show a long-term improvement of dry matter yield after reseeding permanent grassland, mainly because old permanent swards used for renewing often had a relatively good botanical composition. Especially in the seventies, the focus was on methods of renewing and the 'years of depression' by which the gross yields of the newly sown swards mostly were characterized. For that purpose of research, it was not particular necessary to reseed swards with a poor botanical composition. Concerning the characteristic yield depression of newly sown grass, the deterioration period mostly started 1 to 4 years after sowing and occurred as a temporary poor period (Hoogerkamp, 1984). Nowadays such poor periods do not seem to occur anymore, most probably due to the use of more N fertilizer and new grass varieties with a better persistence (Hoogerkamp, 1984).
A field experiment by Hopkins (1990) showed that reseeding old permanent grassland with a diverse botanical composition and less than 30% perennial ryegrass increased the dry matter yield considerably in the first year. In the following years there was only a slight increase (5-10%) at the higher N-levels. However, though reseeding grassland with a poor botanical composition gives an increased dry matter yield, also the reseeding of good old grassland may increase the dry matter yield in the first year considerably. After reseeding permanent grassland of good botanical quality in autumn, an increased dry matter yield in 1973 of 9% on a maritime clay soil, 24% on a peat soil, 25% on sandy soil and 21% on a river clay soil with dry matter yield levels of 13.7 to 16.2 ton per ha has been observed (Luten *et al.*, 1976). Other data suggests that this increase only takes place in the first year after resowing.
Only looking at the result of grassland reseeding based on dry matter yield and in vitro digestibility of grass can lead to the conclusion that the effect of reseeding is limited (Keating & O'Kiely, 2000). However, the beef production of heifers (carcass gain) was 23,6% higher on reseeded grassland compared to the old permanent grassland. Therefore, only looking at dry matter yield or digestible dry matter yield may lead to a wrong estimation of the necessity of resowing grassland. Apart from net animal production, the suitability of grass for silage making is

another important factor in valuating old permanent grassland. Ryegrasses give good quality silages, whereas some indigenous species give poor quality silages (Wilson & Collins, 1980).

7.3 Grassland renovation in practice

7.3.1 Motivation

Although there are differences in grass growing conditions in Northwest Europe because of differences in climate, the motivations for grassland renovation are similar. Decreasing net yields and a disappointing animal performance are the main reasons to consider reseeding. Perennial ryegrass responds better to high N fertilization than permanent pastures and has a relatively high nutritive value which is desirable for intensively managed lactating cows. Intensively managed farms have a high silage production which increases the need for a high level of grass production and the necessity of reseeding. On the other hand, intensive management can increase sward deterioration, caused by relatively heavy cuts and soil compaction by heavy machinery. Under those circumstances as well as under drought and severe winters, sward density decreases, which increases the risk of an invasion of annual meadow grass (*Poa annua*), couch grass (*Elymus repens*) or weeds, like dandelion (*Taraxacum officinale*), docks (*Rumex obtusifolius*) and chickweed (*Stellaria media*). Wet conditions hamper the management which usually causes high yielding cuts. Heavy cuts may cause sward deterioration by poaching and sward destruction by wheel traffic. Grassland is mostly renewed after land reclamation. Furthermore, on peat soils regular leveling may be necessary because of unequally sagging of the soil.

7.3.2 Criteria

In general, criteria for reseeding grassland are subjective and include a poor sward composition, the need for leveling, insufficient dry matter production, high grazing losses and a low animal performance. More specific criteria concerning sward composition, which indicate that renewing may be necessary are: (Conijn *et al.*, 2002):

- The Netherlands: proportion of perennial ryegrass less than 50 % or proportion couch grass more than 10 %.
- Belgium: proportion of couch grass more than 15 %.
- Ireland: proportion perennial ryegrass less than 40 % and proportion of *Agrostis spp* and other undesirable species more than 30 % or when more than 20 % of the surface is shaded by Rumex obtusifolius. Routinely testing of silage quality can also provide an indication whether to resow or not.

7.3.3 Methods

In Belgium and the Netherlands grass is usually reseeded during August and September, because of favourable weather conditions in autumn in contrast to drought risk in spring. It is generally recommended to kill off the old sward with glyfosate, if the swards contains couch grass and to prevent old sward rests from regrowing. It is preferred to destroy the old sward with a rotary tiller to enhance the breakdown of the old vegetation and to prevent the old sward being brought up again during cultivation. Tillage is followed by ploughing, usually to a depth of 20 to 25 cm. If necessary, ploughing is followed by leveling. Shortly before sowing, a seed bed will be prepared; on heavy soils with a rotary harrow and on sandy soils with a cultivator. In the Netherlands mostly 25 to 40 kg seed ha^{-1} is used. Soil analyses is recommended as well as an application of required nutrients. Concerning N, this is 30 kg N ha^{-1} for the first cut. Direct sowing into the old sward is only done on heavy clay soils and peat soil to retain a firm soil.

An alternative for ploughing is shallow cultivation, which has the following advantages:

- It is a good alternative for soils which are not suitable for ploughing
- It will retain relative immobile soil nutrient (P) at the soil surface
- Stones are not brought up to the surface
- Better aggregate stability
- It prevents soil erosion in strongly hilled areas

7.4 Economics

Total costs for renewing grassland depend on soil type, additional fertilizer needs and additional soil leveling and vary between countries (Conijn *et al.*, 2002). In the Netherlands the basic costs vary from 557 € ha^{-1} on peat soils to 826 € ha^{-1} on heavy clay soils. Additional fertilizer and soil leveling may increase the costs to 734 € ha^{-1} (peat soils) and 1392 € ha^{-1} (heavy clay soils). In Belgium the costs of grassland renovation also show a high variability. Average total costs are estimated at 365 € ha^{-1}. Because on average every six years grassland is renewed, new grassland should produce 5 to 7% more than old permanent grassland. In Germany, reseeding, using a non-selective herbicide and ploughing cost 291 € ha^{-1}. In Ireland total costs for grassland reseeding is 480 € ha^{-1} for conventional ploughing, 455 € ha^{-1} for minimum cultivation (2 runs power harrow) and 460 € ha^{-1} for minimum cultivation (single-pass system). In grass to grass resowing during autumn the loss of production is around 2 t DM/ha, which indirectly costs 100 € ha^{-1}. The costs of establishing grass conventionally is estimated at 357 £ ha^{-1} (= 510 € ha^{-1}). This is written off over 7 years for a silage sward and 15 years for a grazed sward.
The benefits of resowing are mainly the increase of net grass production. Therefore, a model which approaches the grass production over time has been developed (Hoving *et al.*, 2003). In the model, the gross production declines with an increasing content of undesirable grass species. Furthermore, the nutritive value of grass and the intake of grass by cows with grazing and silage are depending on the content of undesirable grasses which results in a net grass production. An example of the results of this model has been given in Figure 1 for a drought sensitive sandy soil over 30 years. Based on the model, the 'Grassland Reseeding Guide' was developed, a computer program available on the internet site of Applied Research of the Animal Sciences Group (www.asg.wur.nl). This program calculates a cost/benefit analysis, depending on factors such as actual costs, present content of desirable grasses and clover, soil type, groundwater level, irrigation and N fertilization level. The tool provides an economical balance, a nitrogen balance and a recommendation whether to resow or not.

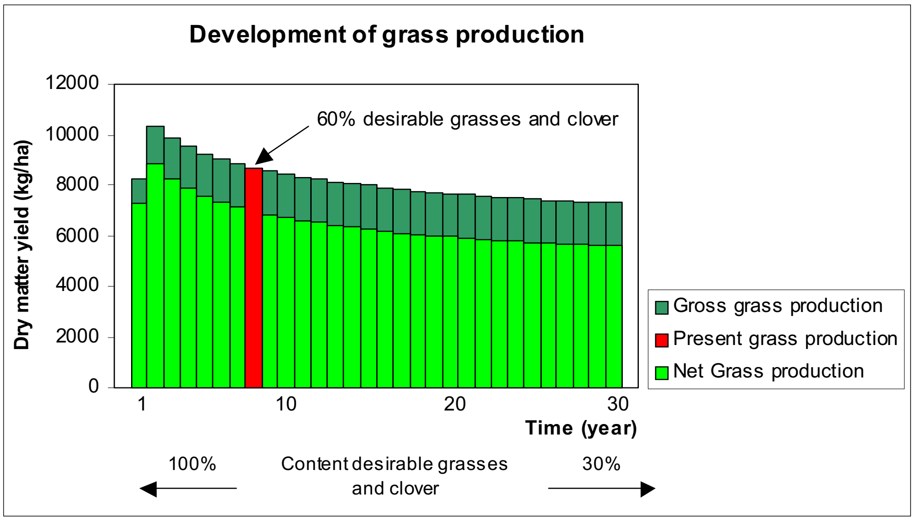

Figure 1. Model approach of the development of grass production (dry matter) for a long term period. Example for a drought sensitive sandy soil.

7.5 Conclusions and key questions

Conclusions

- There are no reliable data characterizing the motivations of farmers
- The botanical composition is the most important criterium
- Level of costs differs between countries
- A cost/benefit analysis is difficult to calculate

Key questions

- How does the botanical degradation of a grass sward develop?
- How does the nutritive value alter?
- What is the net uptake during grazing and winterfeeding?

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8. Farm management and economics – grass in rotation with arable crops

I.E. Hoving

Animal Sciences Group, Wageningen UR, Applied Research, PO Box 2176, NL-8203 AD Lelystad, the Netherlands

8.1 Introduction

Dairy farmers rotate grassland with fodder crops like maize, lucerne or fodder beet mainly because of climatic reasons that have impact on the cost and benefits of production (Conijn *et al.*, 2002). Denmark and Northern Germany are countries in which rotational farm systems are common practice. In the more eastern located countries of Northwest Europe winters are relatively long and harsh and summers are relatively dry. This makes it necessary for dairy farmers to store high quantities of conserved feed, with a good nutritive value. Fodder crops like corn, maize fodder beet and lucerne can be produced well under dry conditions and have a high nutritive value. Farmers also grow grass and fodder crops in rotation because of historical reasons. For example, Denmark has a long tradition of using grassland in crop rotation, whereas in Belgium and the Netherlands farmers traditionally supplement grass rations with maize, which is mostly grown in monoculture. Rotation of short grass leys is increasingly important, because of limitations of N-fertilizer and introduction of clover in grass swards, especially in organic farming but also in conventional farming.

8.2 Agronomic reasons for placing grass in rotation

Because of the short growing season in Northwest Europe, combined with desired year-round high milk productions, a provision of conserved feed with a good nutritional quality is necessary. With good growing conditions, for example on clay soils with a high soil fertility and not sensitive for drought, it is very well possible to achieve high milk productions on silage-based rations, supplemented with concentrates. With poorer growing conditions, however, for example on drought sensitive sandy soils, grass production is mainly needed for grazing, whereas fodder crops give relatively high productions. Growing fodder crops may therefore be advantageous. Especially maize has a better N-utilization and a better water use efficiency than grass, although also maize is sensitive for drought especially during flowering. Therefore, corn crops, fodder beet or lucerne may be a good alternative, if it is not possible to irrigate.

Historically, in Denmark and also in Northern Germany grassland is rotated with arable crops, which is mainly because of the high positive residual effects on the following grain crop in terms of both nitrogen and disease control and to a high grass yield in newly established swards (Conijn *et al.*, 2002). The arable crops usually are winter wheat or spring barley for grain, spring barley for whole-crop-silage, fodder beet and maize. In Belgium and the Netherlands on the drought sensitive sandy soils farmers mainly grow maize to increase total forage production. Due to high inputs of especially manure, maize was mainly grown in monoculture and it was not necessary to use rotation. Nowadays, the EU nitrate policy forces farmers to reduce the amount of animal excreta to 170 kg ha^{-1} and soil fertility is increasingly important to maintain a sufficient production level. Grass to maize rotation offers possibilities for growing maize in terms of production. Positive effects could be an increased N delivery and organic matter content of the soil, higher moisture contents and a better soil structure. Grass - maize - wheat rotations are also used in France.

The restriction of the EU nitrate policy stimulates the re-introduction of white clover in grass swards. Depending on the soil conditions and weather circumstances clover will eventually disappear from older grassland and cultivation is necessary to increase the clover content. Introduction of clover in a perennial grass sward by resowing an old grass sward often is not successful, due to the high N mineralization and diseases like clover cyst nematode and free living nematode. Short grass leys in rotation are more suitable to provide a high clover content than permanent grasslands, which is generally experienced in Denmark. In Belgium and the Netherlands organic farmers destruct grass – clover swards after it has an age of 3 to 7 years depending on the clover content (personal communication, N. van Eekeren). The most common rotation is grass/clover– maize – wheat; usually red clover under cutting conditions and white clover under cutting/grazing conditions. Generally, if the clover content of the remaining grass/clover swards is sufficient, farmers try to extend the arable period by growing maize two years on a row, mainly for extending also the grass period. However, if it is difficult to maintain a sufficient clover content, farmers will shorten the arable period to only one year by growing winter wheat or spring wheat, depending on the moment of destruction of the old grass in the year. In this case wheat is only used as an intermediate crop to reduce the disease pressure of nematodes, to improve the soil structure and to reduce the presence of weeds such as dandelion (T*araxacum officinale*), docks (R*umex obtusifolius*) and couch grass (E*lymus Repens*). However, the amount of clover cysts nematodes is still relatively high in the first year after destruction (Nevens & Reheul, 2002). Thus, a short interruption of grass–clover leys of one growing season does not seem to push back nematodes sufficiently.

8.3 Economics

Besides the practical reasons for grass in rotation to arable crops, it is also important to have insight in the costs of rotation also. To make a cost / benefit analysis generally two types of rotational systems are characterized here:

1. Rotation grass to arable crops which are intended for sale on commercial markets, such as flower bulbs, potatoes or wheat for grain.
2. Rotation grass to fodder crops meant for supplementing grass in rations.

Ad 1.
Bussink *et al.* (2000) studied the possibilities for rotation of grass to commercial arable crops on dairy farms on a young sea clay soil, in the Flevopolder in the Netherlands. The conclusion was that rotation increased the economic results, even if the Dutch legislation restrictions on N-surplus were taken into account. However, rotation demands a complex mineral management. Rotating grass to commercial arable crops is beneficial for the following crop because of fertilizer effects, positive effects on the soil structure and reduced disease pressure of predominantly nematodes. Furthermore, newly established swards have relatively high grass yields (Denmark, see Conijn *et al.*, 2002). However, the fertilizer effect of grassland destruction for following crop depends on the moment of destruction and the moment of seeding of the following crop.

Ad 2.
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% more than continuously grown maize. Due to the late harvest of maize, the new grass sward was established in spring of the next year. Consequently, the yield of first year grassland was 19% lower than the yield of the older swards. The grass-maize rotation system was therefore financially unattractive in comparison with a system of permanent grassland and continuous maize cropping, also because of the additional costs of grassland renovation. Grass - fodder crop rotation is probably only worthwhile when the inputs of N-fertilizer and chemical pesticides are limited, which is usually the case in organic farming. In those low input farming systems there is a substantial need for protein in the dairy ration, which means that grass with a high protein content should be produced. Furthermore, in organic farming, grazing is restricted so a substantial grass area is required and purchasing protein is limited. Clover provides protein and rotation with arable crops enables the retention of a sufficient clover content, as outlined before. The practical question for farmers is: when is destruction of the old grass/clover sward recommended and how many years of interruption with arable crops is needed. To answer these questions and to make cost/benefit calculations possible, it is necessary to get more insight in the increase of clover nematodes and the production of newly established swards related to the clover content. An additional question concerning cost/benefit analysis might be whether grass/ clover should be sown with a cover crop or not.

8.4 Conclusions

Main reasons for rotation are:

- Climate and soil type, which have impact on the length of the growing season (winter provision) and the growing conditions
- Positive effects on grass and crop production
- The introduction of clover in a perennial grass sward
- Maintaining soil fertility

Key questions

- How long should the grass and arable phase be for optimum productivity, especially related to the clover content in mixed grass/clover swards?
- What economic benefits may be expected from using rotations?
- How does the clover nematodes population develop over the years?
- Should grass-clover be reseeded with or without a cover crop?

8.5 Literature

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Van Eekeren, N., 2003.
Louis Bolk Institute, The Netherlands.

9. General conclusions and follow-up

J.G. Conijn & H.F.M. Aarts

Plant Research International B.V., P.O. Box 16, 6700 AA Wageningen, the Netherlands

9.1 Working hypothesis

During the two meetings in Wageningen and Kiel, the Working Group has formulated a working hypothesis on the processes that occur around grassland ploughing and resowing. The figure below illustrates this hypothesis, in which grass yields and nutrient losses are negatively correlated.

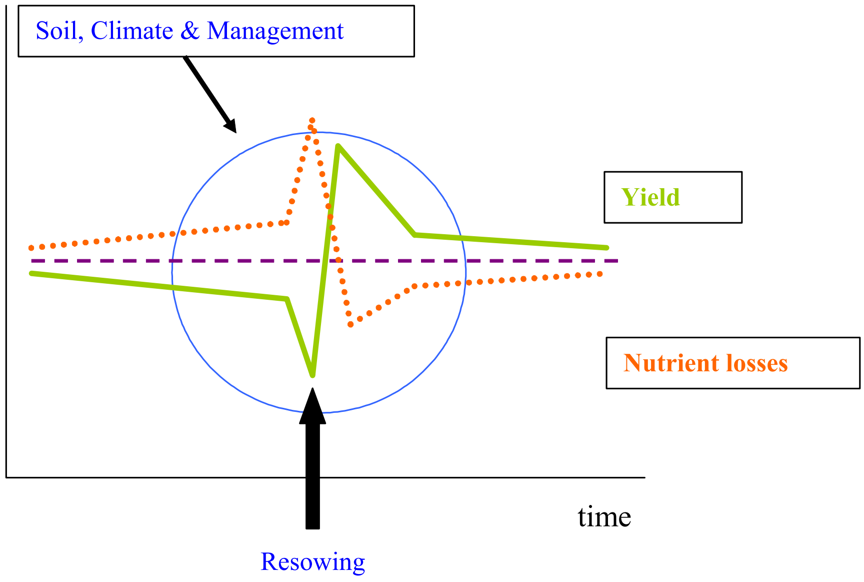

Figure 1. Hypothesised development of yield (green line) and nutrient losses (orange line) before and after renovation of old grassland.

For grass yields: decreasing yields with grassland age, loss of production in the year of ploughing, increased yields in the first year(s) after resowing followed by higher production levels of the new sward relative to the old sward. Yield may be expressed in terms of dry matter, nitrogen, protein or metabolic energy and refers to net yield or net intake.

For nutrient losses: increasing losses with grass sward ageing, a high risk of losing nutrients shortly after ploughing, lower emissions in the first years after resowing followed by lower levels of nutrient losses relative to the old sward.

A very important aspect in the hypothesis is the different response of grassland to resowing in different parts of Northwest Europe due to different soil-climate conditions and farm management. Understanding the relationship between soil, climate, management, and the extent of benefits or losses, is crucial for the development of pratical guidelines for farmers and decision-makers regarding grassland renovation. It is a challenge for scientists to collect and compare results from various regions in Europe, to understand the processes that cause the differences and in this way contribute to sustainable grassland management. International collaboration should therefore be promoted.

The hypothesis has already proved to be useful in the discussions, because it facilitates the comparison of data and processes from various parts of Northwest Europe (see f.i. section 4.1).

9.2 Agronomic and environmental questions

9.2.1 Introduction

In this section main questions, from both an environmental and agricultural point of view, are presented, as turned up during the second meeting of the EGF working group 'Grassland Resowing and Grass-arable Rotations' in Kiel (27-28 February 2003). Coming years, the working group tries to combine available knowledge in Northwest Europe to formulate answers on these questions, and will make proposals for additional research to fill the knowledge gaps. Questions are related to the performance of the soil/crop component of the farm and to the performance of the farm as a whole.

Resowing of grassland and rotating grass and arable crops do influence performance of the soil, for instance by affecting soil processes (like mineralisation). Changes in performance can be judged as negative (like an increased risk for leaching, caused by an increased mineralisation after ploughing grassland) or positive (like an improved soil structure, caused by cultivation, leading to an increased rooting depth or rooting intensity and therefore an improved utilization of nutrients and water). The balance between negative and positive effects depends on location-specific circumstances (climate, soil type, hydrology), as they are linked to soil processes, on management and of course on the agricultural and environmental goals (f.i. will water be collected for drinking water or do nature reserves surround?). Soil performance does influence crop and cattle performance by effecting crop growth, leading to changes in yield levels, seasonal distribution, stability of yields and herbage quality. Costs, related to grassland renovation, and soil/crop/cattle performance will influence farm performance (like needs for purchases of feeds and fertilizers, affecting income and surpluses on farm nutrient balances).

9.2.2 Questions

Soil/crop performance

Cultivation will change soil conditions. Changes in physical conditions affects for instance water holding capacity, leading to more ore less drought sensitivity. Annual input and turnover of organic matter and related nutrients are influenced by changes in crop production (as reaction on changes in soil quality and plant species) and soil processes. As a result organic matter content and crop availability of nutrients will be influenced too. Effects of grassland resowing and rotating grass and arable crops on soil performance presumably depend largely on circumstances (soil type, hydrology, climate). To a certain extent, measures can be taken by the farmer to control effects on soil performance (f.i. time and method of cultivation, length of grass and arable period, fertilization and species choice).

Main questions are:

- What measures can be taken to maintain or improve soil quality (physical, chemical or biological) in relation to crop productivity?
- To what extent can soil quality be changed by cultivation and how long do these changes persist?
- What are the main soil parameters (indicators) to look at?
- To what extent is the soil carbon storage changed by cultivation and how long do these changes persist?
- How is efficiency of fertilizer utilization influenced?
- How should fertilization be adapted?
- To what extent is the risk of nutrient emissions changed by cultivation and how long do these changes persist?
- Is there a change in type of nutrient loss: to ground water, surface water or atmosphere?
- What measures can be taken (or should be avoided) to reduce the risk for emissions to an acceptable level?
- Does grass/arable crop productivity increase and how long does it persists?
- Does grass/arable crop quality improve and how long does it persists?

- How long should the length of the grass and arable period in a rotation be?
- How is the resistance of crops against drought and diseases influenced?
- How does clover react on reseeding and grass-arable rotations?

Farm performance

A farming system has to meet economic and social goals within environmental restrictions. The land use system (permanent grassland or grass - arable rotations) and the management of the system (for instance reseeding, length of grass and arable period, fertilisation plan) play an important role in the performance of the whole farming system.

Main questions are:

- Will the need for additional feed (concentates and purchased roughage) be influenced?
- Will the need for additional fertilizers (mineral of purchased organic fertilizers) be influenced?
- Will stability of crop production be influenced?
- Do farm nutrient surpluses change?
- What are the financial costs and benefits?
- Under what farm conditions (intensity, soil type, climate, availability of labour) is a grass - arable rotation more attractive than permanent cropping?
- How to decide about reseeding of permanent grassland (indicators)?

9.3 Follow-up

In Kiel appointments have been made on the contributions for the 20th General Meeting of the EGF in Luzern, in June 2004. The Working Group will present its work in Luzern during a special session on 'Grassland Resowing and Grass-arable Rotations', by means of both oral and poster presentations. The next meeting of the Working Group will also be in Luzern during the General Meeting of the EGF. Further collaboration and future plans will be discussed then.

Appendix I.
List of participants

Country	Name	Postal address	Email address
Germany	Friedhelm Taube (chairman)	University of Kiel Agricultural Faculty Holzkoppelweg 2 24118 Kiel	ftaube@email.uni-kiel.de
	Michael Wachendorf	University of Kiel Agricultural Faculty Holzkoppelweg 2 24118 Kiel	mwach@email.uni-kiel.de
	Hagen Trott	University of Kiel Agricultural Faculty Holzkoppelweg 2 24118 Kiel	htrott@email.uni-kiel.de
	Michael Kelm	University of Kiel Agricultural Faculty Holzkoppelweg 2 24118 Kiel	mkelm@email.uni-kiel.de
	Martin Gierus	University of Kiel Agricultural Faculty Holzkoppelweg 2 24118 Kiel	mgierus@email.uni-kiel.de
	Ralf Loges	University of Kiel Agricultural Faculty Holzkoppelweg 2 24118 Kiel	rloges@email.uni-kiel.de
	Nicola Fohrer	Fachabteilung Hydrologie und Wasserwirtschaft des ÖZK Olshausenstr. 40 24098 Kiel	nfohrer@hydrology.uni-kiel.de
	Günther Springob	Institute of Soil Science University of Hannover Herrenhäuser Strasse 2 30149 Hannover	GuentherSpringob@aol.com
France	Francoise Vertès	UMR Sol Agronomie Spatialisation Rennes – Quimper 4 rue de Stang Vihan F – 29000 Quimper	vertes@lerheu.rennes.inra.fr

Country	Name	Postal address	Email address
United Kingdom	David Hatch	Institute of Grassland and Environmental Research North Wyke Research Station Okehampton Devon, EX20 2SB	david.hatch@bbsrc.ac.uk
	Alan Hopkins	Institute of Grassland and Environmental Research North Wyke Research Station Okehampton Devon, EX20 2SB	alan.hopkins@bbsrc.ac.uk
Denmark	Karen Søegaard	Danish Institute of Agricultural Sciences Department of Crop Physiology and Soil Science P.O. Box 50 8830 Tjele	karen.soegaard@agrsci.dk
	Ib Sillebak Kristensen	Danish Institute of Agricultural Sciences Department of Agricultural Systems P.O. Box 50 8830 Tjele	IbS.Kristensen@agrsci.dk
Belgium	Lydia Bommelé	Ghent University Department of Plant Production Coupure Links 653 B - 9000 Gent	lydia.bommele@rug.ac.be
The Netherlands	Sjaak Conijn (secretary)	Plant Research International P.O. Box 16 6700 AA Wageningen	sjaak.conijn@wur.nl
	Frans Aarts	Plant Research International P.O. Box 16 6700 AA Wageningen	frans.aarts@wur.nl
	Idse Hoving	Animal Science Group, Applied Research, Wageningen UR P.O. Box 2176 8203 AD Lelystad	idse.hoving@wur.nl

Appendix II.

Abstract of the first report of the EGF-Working Group 'Grassland Resowing and Grass-arable Rotations'

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.

Reference

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