TOWARDS SUSTAINABLE INTENSIVE DAIRY FARMING IN EUROPE

M. WACHENDORF[1] AND P. GOLIŃSKI[2]

[1]Department of Grassland Ecology and Forage Production. University of Kassel. Nordbahnhofstrasse 1a, 37213 Witzenhausen (Germany). [2]Department of Grassland Sciences, Agricultural University of Poznań. Wojska Polskiego 38/42. 60-627 Poznań (Poland)

SUMMARY

Increased production from grassland has been achieved at considerable environmental costs, including the loss of biodiversity, many wildlife habitats and landscapes. Since the 1980s policy makers in many European countries require that elements of a sustainable forage production be addressed by researchers. In many European countries intensive dairy farms are facing difficulties in achieving these goals, with nitrogen surpluses and losses being a major topic in large parts of northern continental Europe, where sandy soils predominate. Results from two comprehensive studies (experimental farms Karkendamm and De Marke) show the current nitrogen status of forage-based dairy production in this area and identify shortcomings in the production systems which should be improved in the future. Simulations with the worldwide leading modelling system IFSM (Integrated Farming System Model) verify the long-term effects of technological changes and point at potential solutions for the actual dilemma. Among many agronomical factors determining feed production for dairy cows grassland cultivation and renovation is a quite important issue. A literature review indicates that little knowledge exists in many aspects but also shows that the application of good farming practices can reduce the environmental risks for dairy dominated regions.

Keywords: Grassland management, sustainability, nitrogen losses, energy efficiency

INTRODUCTION

Sustainable production systems aim at the integration of social, production and environmental goals, including improved nutrient management and reduced environmental pollution. A suitable balance must be made between minimizing nutrient losses and production costs to provide sustainable production systems. Limited information exists on the management and nutrient flows in grassland agriculture at the whole-farm or systems scale. Most of this type of research has focused on arable cropping systems. In this paper we focus on two themes which are relevant for grassland production in areas with intensive dairy farming where a major environmental issue in the future will be the improvement of nutrient efficiency:

1. *Nitrogen and energy use efficiency in forage production systems* based on data from two recent experimental research efforts which focused on nutrient management in whole-farm systems, and
2. *Efficient grassland cultivation and renovation* as a tool for improvement of feed supply and herbage quality in dairy farms and which also has an impact on environmental issues. The latter is based on a comprehensive review of literature.

FOCUS THEME 1: .NITROGEN AND ENERGY USE EFFICIENCY IN FORAGE PRODUCTION SYSTEMS

Karkendamm Experimental Farm

Multiple interactions influencing nitrogen fluxes in the soil-plant-animal system were studied at the Karkendamm experimental farm in northern Germany (Taube and Wachendorf, 2001). Experiments were established on permanent grassland (Trott *et al.*, 2004; Wachendorf *et al.*, 2004; Lampe *et al.*, 2004) including cutting (i.e., mechanical harvest for hay or silage), grazing, and two mixed systems of cutting and grazing with mineral fertilizer input (0,100, 200, 300, and 400 kg N ha^{-1}) and slurry application (0 or 20 m^3 ha^{-1} at 2.4 kg N m^{-3}). The N surplus across all treatments was linearly related to total N supplied (Fig. 1; Trott *et al.*, 2004). The increase in N surplus per kg N applied was 2.5 times higher in GO than in CO. Thus, to reduce N surpluses in rotational stocking systems, less N must be applied. The inclusion of a silage harvest with rotational stocking systems reduced N surplus and cutting-only systems allowed N application rates beyond 300 kg ha^{-1}. Nitrate leaching losses were strongly affected by the type of defoliation, with nitrate concentrations in the leachate in the CO and SG systems generally below the EU threshold (Wachendorf *et al.*, 2004). Highest concentrations were measured in the grazed-only treatment and intermediate nitrate losses occurred in the mixed systems. The regression in Fig. 1 implies that N surpluses of not more than 30 kg ha^{-1} are acceptable to meet the EU standard for drinking water. Total N_2O emissions measured from the soil surface over an 11-month period ranged from 1.7 to 4.9 kg N ha^{-1}. The lowest N_2O emissions occurred with an application of 100 kg mineral N ha^{-1} and the highest emissions occurred when a combined N supply of slurry (74 kg N ha^{-1}) and mineral fertilizer (100 kg N ha^{-1}) was applied (Lampe *et al.*, 2004). Emissions in winter, primarily during freezing and thawing cycles, made a considerable contribution to the total annual N_2O loss.

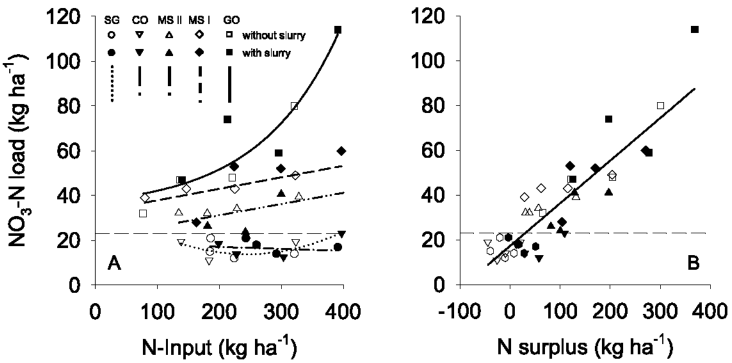

FIGURE 1

Relationship between annual N leaching losses and (A) N-Input (including N from slurry, mineral fertilizer, biological fixation and atmospheric deposition) and (B) annual N surplus on grassland (GO=grazing only; MSI/II=mixed system with one cut and two cuts in spring, respectively, and subsequent grazing; CO=cutting only; SG=simulated grazing) (Wachendorf *et al.*, 2004).

Relación entre las pérdidas anuales de nitrógeno por lixiviación y (A) N-entrada (incluyendo N de purín, fertilizante mineral, fijación biológica y deposición atmosférica) y (B) exceso anual de N en praderas (GO= pastoreo solamente; MSI/II=sistema mixto con uno y dos cortes en primavera, respectivamente, y pastoreo subsiguiente; CO=siega solamente; SG=pastoreo simulado) (Wachendorf et al., 2004).

The efficiency of fossil energy use was determined as the feed net energy yield per unit of fossil energy input in production activities. Energy inputs included both direct (diesel use for field operations) and indirect (fossil energy input in the manufacture and distribution of fertilizers, pesticides, machinery, seeds, etc.) inputs (Kelm *et al.*, 2004). Energy efficiency declined with increasing mineral N fertilizer input and was most pronounced on pastures. A given net energy yield was produced most energy-efficiently in a mixed system (MS1) where additional yield compensated for the higher energy input from increased machinery activities. With increasing grazing intensity, CO_2 emission was reduced whereas N loads increased continuously. The CO_2 emissions were lowest in unfertilised pastures, but increased again with increased input of mineral N fertiliser. The benefit of reduced nitrate leaching loss from cutting systems must be considered along with the significantly lower energy efficiency and higher CO_2 emissions of these systems compared with grazing-only systems (Fig. 2). The selection of the optimal or best production strategy is dependent upon the relative value of each of these factors as determined by the demands of society.

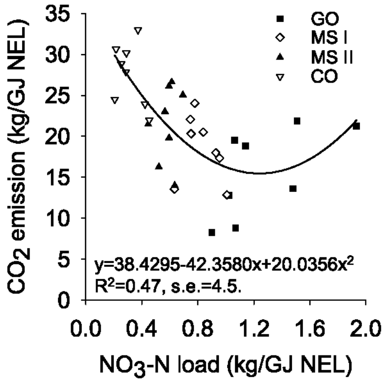

FIGURE 2

Relationship between CO2 emission and nitrate-N load in the drainage water from grassland (GO=grazing only; MS I/II=mixed systems with one cut and two cuts in spring, respectively, and subsequent grazing; CO=cutting only; NEL=net energy lactation) (source: Wachendorf and Taube, 2005).

Relación entre la emisión de CO2 y la carga de NO3-N en el agua de drenaje de pastos (GO= pastoreo solamente: MS I/II= sistemas mixtos con uno o dos cortes en primavera, respectivamente, y pastero subsiguiente; CO= siega solamente; NEL= energía neta de lactación (fuente: Wachendorf and Taube, 2005).

The De Marke Experimental Farm

The De Marke farming system (located near Hengelo in the province of Gelderland, The Netherlands, on a sandy soil) was designed to minimize external inputs of feed and fertilizer and to maximize the use of homegrown feeds and manure. The goal was a high milk production per cow with a minimum number of calves and replacement heifers to reduce feed requirements per unit of milk produced. The farm area consists of 11 ha of permanent grassland and 44 ha of rotated grass and maize. Fields are in grass for 3 years followed by 3 to 5 years of maize. Grass and maize are rotated to stimulate maize growth and to avoid build-up of high organic matter contents with the associated risk of nitrate leaching during decomposition of the organic matter (OM) In the first year after grass, maize is not fertilized. Nitrogen fertilization levels at De Marke, including N from slurry, clover, and the residue of ploughed-under Italian ryegrass and grass sod, are about 40% lower than those on conventional farms. About 75% of the slurry produced is applied to grassland by shallow injection in two to three splits depending on grassland management. Additional inorganic N fertilizers are applied on grassland at a rate of 107 kg N ha^{-1}. Total surplus N of the farm (Table 1) includes NH_3 volatilization, denitrification loss, accumulation in soil organic matter, runoff, and leaching. Average annual surplus from 1993 to 2002 was 146 kg N ha^{-1} and 3 kg P_2O_5 ha^{-1}. The design of the farming system was modified in 2000 (shorter grazing periods and reduced fertilization), which reduced the N surplus to 117 kg N ha^{-1} by 2002. A comparison of the nutrient balance of De Marke to that of an average current farm (on sandy soil in the mid 1990's with a similar milk quota) shows that high nutrient use efficiencies in animal nutrition and crop cultivation allow similar milk production with a lower level of nutrient input.

TABLE 1

Nitrogen balances of the De Marke experimental farm compared to the balances of the average Dutch farm in the middle of the 1990s (source: Hilhorst *et al.*, 2001).

Balances de nitrógeno de la finca experimental De Marke comparados con los balances de la explotación holandesa media a mediados de los noventa (fuente: Hilhorst et al., 2001).

kg N ha-1	**De Marke**		**Average**
	1993-2002	**2002**	**Farm**
Input			
Concentrates	86	87	125
Roughage	8	0	20
Chemical fertilizer	64	35	242
Organic manure	0	0	50
Biological N fixation	11	27	0
Animals	0	0	0
Deposition	49	49	49
Miscellaneous	5	5	0
Total	*223*	*203*	*486*
Output			
Milk	66	64	64
Animals	9	8	14
Roughage	1	0	0
Organic manure	1	0	0
Total	*77*	*72*	*78*
Balance	**146**	**131**	**408**

Computer simulation as a tool for long-term evaluation of farming systems

With computer simulation, many variants of the production system can be easily evaluated, including different climatic regions, soil types, and farm management scenarios. As one of the few system-oriented models the Integrated Farm System Model (IFSM) integrates the many biological and physical processes on dairy and beef farms (Rotz *et al.*, 1999; Rotz and Coiner, 2003; Rotz *et al.*, 2005). Confidence in the simulation results can best be gained by a combination of experimental and modelling evaluations with measured data and information from actual production systems. As an example how the farm model can be applied to extrapolate the experimental results of the Karkendamm study to whole farm systems, a representative dairy farm with the characteristics of farms in this region was simulated using weather data from Kiel, Germany (Table 2). Rotational grazing of the dairy herd had little effect on N import and export from the farm, but N

TABLE 2

Annual feed production and nitrogen flows of a simulated dairy farm* in northern Germany (source: Rotz *et al.*, 2005).

Producción annual de material seca y flujos de nitrógeno de una explotación simulada en el norte de Alemania (fuente: Rotz et al., 2005)*

Production parameter	**No grazing**[§]	**Grazed**[¶]
Feed production (Mg DM)		
Grass silage production	288	144
Grazed forage consumed	0	137
Forage purchased	57	87
Supplemental feed purchased	127	111
Nitrogen flows (kg ha^{-1})		
Nitrogen imported	310	314
Nitrogen exported	82	82
Nitrogen lost by volatilization	80	94
Nitrogen lost by leaching	43	55
Nitrogen lost by denitrification	29	30

* 55 cows (8,000 kg milk cow-1) and 48 replacement heifers on 34 ha of loamy sand soil simulated over weather years 1980 to 2002 for Kiel, Germany.

§ Entire grass crop is harvested, conserved and fed as silage.

¶ About 50% of the annual grass forage consumption is fed through grazing.

losses were greater. To determine the long-term benefits of the management strategies and technologies used at De Marke, three production systems (previous technology, current technology, and the De Marke technology used for nutrient conservation; details in Table 3) were compared for a representative dairy farm of this region (Reijneveld *et al.*, 2000; Aarts *et al.*, 1999). The production system under previous technology reflected inefficient use and cycling of N. Excessive amounts of N, primarily in the form of mineral fertilizer, were imported, causing high losses to the environment. A comparison of current and previous technologies indicates both positive and negative environmental impacts for recent changes in the Dutch dairy industry. A large reduction in N volatilization loss was obtained using the enclosed manure storage and manure injection; however, this caused substantial increases in nitrate leaching and soil denitrification. This occurred because the reduction in volatile loss led to higher levels of soil N, even with a reduction in the use of N fertilizer. Only by fully implementing the practices of De Marke were substantial improvements in N use efficiency achieved through a large reduction in the import of N in fertilizer and feed. Nitrogen volatilization losses were greatly reduced along with reduced leaching and denitrification losses.

TABLE 3

Effect of using technologies for nitrogen conservation on annual milk production and nitrogen balances of a simulated dairy farm in the Netherlands* (source: Rotz *et al.*, 2005).

Efecto del uso de distintas tecnologías para la conservación del nitrógeno en la producción anual de leche y en los balances de nitrógeno de una explotación de vacuno de leche en Holanda (source: Rotz et al., 2005).*

Production parameter	Previous technology†	Current technology‡	De Marke technology§
Milk production (kg cow^{-1})	8,000	8,500	9,000
(kg ha^{-1})			
Nitrogen imported¶	430	364	228
Nitrogen exported¥	89	94	75
Nitrogen surplus$	341	270	153
Nitrogen lost by volatilization	167	62	27
Nitrogen lost by leaching	85	107	55
Nitrogen lost by denitrification	38	45	27

* 55 cows and 48 replacement heifers on 34 ha (26 ha of grass and 8 ha of maize or 17 ha of maize with De Marke technology) of loamy sand soil simulated over weather years 1977 to 2001 for Wageningen, The Netherlands.

† Includes standard barn floor, bottom loaded six-month manure storage, broadcast application, and full-day grazing.

‡ Includes standard barn floor, enclosed six-month manure storage, injection application, and half-day grazing.

§ Includes 9 ha more maize land harvested as high-moisture ear maize and stover, low fertilizer use, a grass catch crop following maize, low emission barn floor with feces and urine separation, an enclosed six-month manure storage, and manure application by injection.

¶ Via fertilizer, feedstuff and animals

¥ Via slurry, feedstuff and animals

$ Nitrogen surplus= Nitrogen imported- Nitrogen exported

Though permanent grassland has a high potential for biodiversity and nature conservation in lowland areas, it was found difficult to achieve these goals in swards managed for high producing dairy cows under the given economic conditions. The prevailing nutrient level and the frequent defoliation favour productivity and forage quality through the dominance of few productive and valuable plant species but usually do not enable rare or endangered plant species to persist in the swards. Results from an extensive survey on 275 German grassland sites confirm that, likewise in organic grassland, such low levels of management intensity necessary for high biodiversity rarely occur (Mahn, 1993). Data from another survey on organic farms suggest that biodiversity decreased with increasing clover content in the sward (Taube et al., 1997). Thus, a significant reduction in grassland management (e.g. through cessation of fertilization, reduction of stocking rates and defoliation frequencies, abandonment of sward improvement measures) like in extensive grazing systems with suckler cows is a prerequisite for an increase in biodiversity.

Conclusions from Focus Theme 1

Intensified forage production systems result in more productive pastures, but also increase the risk of nutrient losses with negative environmental impact. Perennial grasslands, however, have inherent capacities to reduce adverse environmental effects, and appropriate dietary supplementation of livestock and grazing management, tactical fertilizer application, injection of manure, and other means can be used to improve nutrient management in grassland systems. Computer simulation supported by field studies provides a powerful and cost-effective tool for developing, evaluating, and promoting more sustainable grassland systems for commercial livestock production.

FOCUS THEME 2: EFFICIENT GRASSLAND CULTIVATION AND RENOVATION

In sustainable forage production systems the grassland cultivation (resowing of permanent grassland after ploughing and establishment of temporary grassland in rotation with arable crops) and renovation (different methods of permanent sward improvement) play an important role. The demand for large quantities of high-quality forages occurs primarily in dairy farms because one of the prerequisites to maintain profitability in milk production and to utilise the genetic potentials of cows is adequate herbage characterized by excellent quality. Unfortunately, in many regions of European countries with unfavourable weather (e.g. droughts, flooding, frosts and other negative effects of winter) and/or unfavourable soil conditions (e.g. compaction), degradation processes regularly occur on grasslands. One of the indicators of the degradation of permanent meadows and pastures is the decline in the sward of the proportion of valuable forage grasses and legumes and the invasion of species unwelcome from the nutritional point of view (weeds) as well as the deterioration of the sod quality. Decreasing herbage yields and disappointing animal performance are the main reasons to consider grassland renovation. The renovation of grasslands should aim at developing a permanent botanical composition of the sward which becomes fine-tuned to the site yield potential. Many authors have reported that ploughing and resowing is the fastest method of re-establishment of degraded grasslands. Possible alternatives to ploughing are: shallow cultivation and oversowing, or overdrilling syn. direct drilling (Goliński, 2003). Results of numerous investigations indicate that grassland renovation had a positive impact on the herbage quality rather than the yield. Goliński and Kozłowski (2000) came to the conclusion that overdrilling increased yield and the chemical composition of the herbage, but no significant differences were observed in the case of production cost of 1 kg DM. The herbage with higher protein and energy concentration used to feed dairy cows allowed a reduction in concentrate rations in individual farms by 200-289 kg head^{-1} annually. However, the employed renovation methods and techniques can affect the environment considerably and, therefore, it is essential to carry them out in accordance with good farming practices. Particularly, ploughing and reseeding of grassland has become increasingly questioned with regard to environmental aspects such as nutrient loss and soil fertility. It is necessary to develop management rules for grassland management, e.g. renovation, which are acceptable for both farmers and society (Kemp and Michalk, 2005).

This was the main reason why, during the 19th EGF General Meeting in La Rochelle, France, a Working Group on Grassland Resowing and Grass-arable Rotations was officially launched (Taube and Conijn, 2004). Within the framework of this Group, two workshops have already been held, one in Wageningen and the other in Kiel, and two reports from these meetings have been published (Conijn *et al.*, 2002; Conijn and Taube, 2003). The basic working hypothesis of the Group is that grassland productivity declines with increasing age of the sward and that yield decreases in the year of grassland renewal, but increases during the first production years after cultivation. Nitrogen losses are also likely to increase due to increased mineralisation after ploughing. A very important aspect in the hypothesis is the different response of grassland to resowing in different parts of Europe due to different soil-climate conditions and farm management (Taube and Conijn, 2004). Knowledge about this interactions lead to specific strategies in grassland renovation, e.g. traditional methods based on ploughing are applied mainly on mineral soils, whereas on organic soils the application of non-selective herbicides and direct drilling is preferred in order to prevent a boost in mineralisation, and to reduce nitrate leaching and weed ingression.

NUTRIENT CYCLING, INCLUDING EMISSIONS TO THE ENVIRONMENT

Most of the total soil nitrogen is organic N and its rate of accumulation under grassland is approximately linear in the early years of a sown ley (Tyson *et al*., 1990). Sward type, intensity of management and environmental factors affect the rate of soil N accumulation following resowing. All these factors 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). In established leys and permanent swards, N mineralisation proceeds at rates influenced by agricultural management, e.g. lime applications, changes to drainage status, inputs of manures and other nutrients as well as soil type, soil biota, sward composition, available water capacity and climate (Hatch *et al*., 2003). After grassland resowing, increased N mineralisation occurs due to exposure of organic matter to microbial decomposition and increased aeration. Ploughing short term leys released 100-250 kg N ha^{-1}, according to the age of the ley and the soil type (Johnston *et al*., 1994). Okruszko (1991) reported, that in the case of peat soil under conditions of a grass/arable crop rotation and low moisture content, 357 kg N ha^{-1} was released annually from a field of temporary grassland, while on permanent grasslands, but with higher moisture content, N mineralisation amounted to 138 kg ha^{-1}. This nitrogen 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 negative consequences for sward performance and the wider environment (Hatch *et al*., 2003). The huge N-pool in grassland mineralized with cultivation presents a potential environmental hazard but when using good management practices such as spring ploughing and catch crops, the release of N can be controlled and nitrate concentrations in leachates may be kept below the EU Drinking Water Directive upper limit of 50 mg l^{-1}. Results of a study by Davies *et al*. (2001) 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. After cultivation of grassland, growing arable crops with a high N uptake capacity will decrease the risk of 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. In agricultural systems the choice of the crop following grassland is normally 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 uneconomic (Hatch *et al*., 2003).

Organic matter mineralisation in grassland renovation depends on the techniques used for cultivation and management of the subsequent sward. Six *et al*. (2002) confirmed the beneficial effect of minimal tillage operations compared with conventional ploughing in terms of decreasing soil N and C mineralisation and hence the likelihood of reducing nitrate-N leaching losses to surface and ground waters and CO_2 emissions to the atmosphere. The results of Loiseau *et al.* (1992) showed that the decrease of OM was stronger after rotavation than after direct drilling. After mechanical preparation, part of the OM evolved to the fine OM particle size fraction below 200 µm. carbon loss as CO_2 was also higher in intensive soil preparation: 11 (control), 43 (direct drilling) and 52 t C ha^{-1} (rotavator). Studies by Goliński and Kozłowski (2000) on the effects of renovation method on soil chemical composition showed only a slight difference in the content of mineral nitrogen between the overdrilled area and the control. Increases in the content of mineral nitrogen ($N\text{-}NO_3 + N\text{-}NH_4$) occurred in the remaining surfaces ranged from 4.2 to 8.7 kg ha^{-1}. This can indicate minimal damage of the sod by working parts of the seed drill in the process of overdrilling and reduced oxygen availability in soil which prevents accelerated mineralisation of OM.

Timing of grassland resowing plays an important role in sustainable forage production. Spring, rather than autumn, cultivation is suggested as a means of decreasing nitrate leaching. Shepherd *et al.* (2001) reported that the effect of spring ploughing for reseeding was relatively short-term and did not cause increased leaching in the following autumn, whereas autumn ploughing and reseeding leached 60-350 kg N ha^{-1}. Timing of grassland cultivation can also have environmental implications other than N leaching, including effects on gaseous emissions, habitats for wildlife, carbon sequestration and soil erosion (Hatch *et al.*, 2003). In The Netherlands ploughing of grassland might contribute significantly to the emission of N_2O. Measurements on clay soil indicate, that compared to permanent grassland, N_2O emissions were 7 and 113 times higher after ploughing in spring or autumn, respectively (Schils *et al.*, 2002). Phosphorus dynamics in the context of grassland cultivations have received relatively little attention. However there is evidence that tilled grassland results in a short and long term increase in soluble P in the soil profile, presumably related to increases in mineralisation through altered patterns of wetting/ drying and increased soil aeration (Turner and Haygarth, 2001).

Soil quality and water balance

The effects of grassland renovation on soil quality and the subsequent effects on other factors are variable and usually hard to quantify. Grassland renovation of permanent grassland has positive effect on the soil quality of sandy (Schils *et al.*, 2002) and clay soils and a negative effect on the soil quality of peat soils. Grassland ploughing influenced soil OM dynamics, the rooting capacity, the water holding capacity, the bearing capacity and the susceptibility to soil compaction. On peat soils, the physical qualities of the soil, such as soil aggregate stability and bearing capacity are generally negatively affected at grassland renovation. Ploughing up grassland for resowing or conversion to arable has a significant impact on soil biodiversity, e.g. cultivation reduces the number of macrofauna such as earthworms in soil (Pérès *et al.*, 2002). Conversion of grassland to arable land usually causes a strong release of soil C. Eriksen and 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. In agreement with other long observations, C accumulation is half as slow as the C release occurring after the grassland is ploughed (Vertès *et al.*, 2003). Roots are recognized to be an important factor of soil quality and also play a major role after ploughing. Grass roots are more resistant to degradation than roots of annual crops because of higher contents of lignin and phenolic compounds. Grass roots are also well protected from degradation within the undisturbed soil matrix, where high microbial biomass activity promotes aggregation and soil structural stability (Six *et al.*, 2002). Because the C mineralisation for roots is significantly lower in comparison with the aerial organ tissues for several different plant species, the soil OM coming from roots would be found in significant proportions in the soil and has a particular dynamic, which would deeply affect physical, chemical and biological characteristics of the soil during the months following resowing (Vertès *et al.*, 2003).

Conclusions from Focus Theme 2

Ploughing of grassland followed by reseeding is a common strategy to maintain productive grass swards. However, grassland cultivation is being more and more challenged by increasing demands of legislation and society in terms of reduction of nutrient losses, conservation of biotic diversity, protection against erosion and carbon sink. Science is challenged to provide sustainable solutions but few systematic experimental studies into the effects of grassland renovation on environmental and agronomic parameters currently exist in Europe. Identification of farmers' motives for grassland renovation would help to develop scientifically sound and practically applicable criteria to support farmers in decisions on grassland renovation. There is a particular need for a quantification of the effects of grassland renovation on nutrient cycling in the plant-soil system and on DM yield, herbage quality and animal performance, with respect to soil type, renovation strategy and sward management. The goal of the research efforts should thus be the development of optimised management strategies which ensure minimum agronomic and environmental risks during grassland renovation.

Perspectives of sustainable forage production in Europe

The perspectives of sustainable forage production are tightly interlinked with European agricultural policy. The 2003 reform of the CAP with its new support system, including decoupling, modulation and cross-compliance, aims at enhancing the sustainability of agro-ecosystems. Regarding the possible consequences for grassland production, it is necessary to differentiate between high- and low-input production systems. It is most likely that areas with high-yielding grassland nowadays will be managed with orientation towards production in the future as well. The main environmental issue here will be the improvement of nutrient efficiency. An increased knowledge in this field will be necessary and all measures available have to be utilised to achieve this goal. The fact that payment will be decoupled from production may ensure that landscapes in low-forage yielding areas (mainly mountains) will remain open, but the required minimum management will promote very extensive farming systems or even may fail to maintain a satisfactory forage production and use due to low quality of the herbage. More research should be directed towards alternative uses of grassland (e.g. biomass for energy production) which is becoming of increased interest.

REFERENCES LIST

AARTS, H.F.M.; HABEKOTTÉ, B.; HILHORS, G.J.; KOSKAMP, G.J.; VAN DER SCHANS, F.C.; DE VRIES, C.K., 1999. Efficient resource management in dairy farming on sandy soil. *Netherlands Journal of Agricultural Science*, **47**, 153-167.

CONIJN, J.G.; TAUBE, F. (eds), 2003. *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'. Plant Research International B.V., Report 2, 78 pp. Kiel (Germany). 27-28 February, 2003

CONIJN, J.G., VELTHO,F.G.L.; TAUBE, F. (eds), 2002. *Grassland resowing and grass-arable crop rotations.* International workshop on agricultural and environmental issues. Plant Research International B.V., Report 1, 128 pp. Wageningen (The Netherlands). 18-19 April, 2002.

DAVIES, M.G.; SMITH, K.A.;VINTEN, A.J.A., 2001. The mineralisation and fate of nitrogen following ploughing of grass and grass-clover swards. *Biology and Fertility of Soils*, **33**, 423-434.

ERIKSEN, J.; JENSEN, L.S., 2001. Soil respiration, nitrogen mineralisation and uptake in barley following cultivation of grazed grasslands. *Biology and Fertility of Soils*, **33**, 139-145.

GOLIŃSKI, P., 2003. Effectiveness of pasture overdrilling with *Lolium perenne* using different methods of sod preparation. *Grassland Science in Europe*, **8**, 134-137.

GOLIŃSKI, P.; KOZŁOWSKI, S., 2000. Role of grassland overdrilling in the increase of feed economical efficiency and protection of meadow soil. *Grassland Science in Europe*, **5**, 191-193.

HATCH, D.J.; HOPKINS, A.; VELTHOF, G.L., 2003. Nitrogen and phosphorus cycling in grass-to-grass resowing and grass-arable rotations. In: *Grassland resowing and grass-arable crop rotations – consequences for performance and environment*, Report **2**, 5-23. Eds. J.G. CONIJN, F. TAUBE. Second workshop of the EGF-Working Group 'Grassland Resowing and Grass-arable Rotations'. Plant Research International B.V.. Kiel (Germany). 27-28 February, 2003.

HILHORST, G.; OENEMA, J.; VAN KEULEN, H., 2001. Nitrogen management on experimental dairy farm 'De Marke': Farming system, objectives and results. *Netherlands Journal of Agricultural Sciences*, **49**, 135-151.

JOHNSTON, A.E.; MCEWEN, J.; LANE, P.W.; HEWITT, M.V.; POULTON, P.R.; YEOMAN, P.P., 1994. Effects of one to six year old ryegrass clover leys on soil nitrogen and on the subsequent yields and fertilizer nitrogen requirements of the arable sequence winter wheat, potatoes, winter wheat, winter beans (*Vicia faba*) grown on a sandy loam soil. *Journal of Agricultural Science, Cambridge*, **122**, 73-89.

KELM, M.; WACHENDORF, M.; TROTT, H.; VOLKERS, K.; TAUBE, F., 2004. Performance and environmental effects of forage production on sandy soils. III. Energy efficiency in forage production from grassland and maize for silage. *Grass and Forage Science*, **59**, 69-79.

KEMP, D.R.; MICHALK, D.L., 2005. Grasslands for production and the environment. In: *Grassland: a global resource*, 193-208. Ed. D.A. MCGILLOWAY. Wageningen Academic Publishers. Wageningen (The Netherlands).

LAMPE, C.; DITTERT, K.; WACHENDORF, M.; SATTELMACHER, B.; TAUBE, F., 2004. 15N traced nitrous oxide fluxes from fertilised grassland soils. *Grassland Science in Europe*, **9**, 334-336.

LOISEAU, P.; EL HABCHI, A.; DE MONTARD, F.X.; TRIBOI, E., 1992. Indicateurs pour la gestion de l'azote dans les systèmes de culture incluant la prairie temporaire de fauche. *Fourrages*, *129*, 29-43.

MAHN, O., 1993: Untersuchungen zur Vegetation von biologisch und konventionell bewirtschaftetem Grünland. *Verhandlungen der Gesellschaft für Ökologie*, **22**, 127-134.

OKRUSZKO, H., 1991. Effect of the utilisation way on peat soil and phenomena and difficulties connected therewith. *Biblioteczka Wiadomości IMUZ*, **77**, 105-118. (in Polish with English summary).

PÉRÈS, G.; LAMANDÉ, M.; CLUZEAU, D.; MARMONIER, P.; HALLAIRE, V.; CURMI, P.; DELERUE, J.F., 2002. Influence on anthropic constraints on earthworms community, macroporosity and hydrodynamic functioning. *Proceedings of the 7th International Symposium on Earthworm Ecology*, 1-6. Cardif (Ireland). 1-6 September, 2002.

REIJNEVELD, A.; HABEKOTTÉ, B.; AARTS, H.F.M.; OENEMA, J., 2000. Typical Dutch; view on variability in Dutch dairy farming. Report No 8, Plant Research International, 87 pp. Wageningen (The Netherlands). (in Dutch).

ROTZ, C.A.; TAUBE, F.; RUSSELLE, M.; OENEMA, J.; SANDERSON, M.A.; WACHENDORF, M., 2005. Whole-Farm Perspectives of Nutrient Flows in Grassland Agriculture. *Crop Science* (in press)

ROTZ, C.A.; COINER, C.U., 2003. Integrated Farm System Model, Reference Manual [Online]. Available at http://pswmru.arsup.psu.edu. Verified 3 September, 2004.

ROTZ, C.A.; SATTER, L.D.; MERTENS, D.R.; MUCK, R.E., 1999. Feeding strategy, nitrogen cycling, and profitability of dairy farms. *Journal of Dairy Science*, **82**, 2841-2855.

SHEPHERD, M.A.; HATCH, D.J.; JARVIS, S.C.; BHOGAL, A., 2001. Nitrate leaching from reseeded pasture. *Soil Use and Management*, **17**, 97-105.

SCHILS, R.L.M.; AARTS, H.F.M.; BUSSINK, D.W.; CONIJN, J.G.; CORRÉ, W.J.; VAN DAM, A.M.; HOVING, I.E.; VAN DER MEER, H.G.; VELTHOF, G.L., 2002. Grassland renovation in the Netherlands; agronomic, environmental and economic issues. In: *Grassland resowing and grass-arable crop rotations*, Report **1**, 9-24. Eds. J.G. CONIJN, G.L. VELTHOF, F. TAUBE. International workshop on agricultural and environmental issues. Plant Research International B.V.. Wageningen (The Netherlands). 18-19 April, 2002.

SIX, J.; FELLER, C.; DENEF, K.; OGLE, S.; SA MORAES, J.C.; ALBRECHT, A.; 2002. Soil organic matter, biota and aggregation in temperate and tropical soils – effects of no-tillage. *Agronomie*, **22**, 755-775.

TAUBE, F.; CONIJN, J.G., 2004. Grassland renovation in Northwest Europe: current practices and main agronomic and environmental questions. *Grassland Science in Europe*, **9**, 520-522.

TAUBE, F.; WACHENDORF, M.; GREEF, J.M.; WULFES, R., 1997. Perspektiven semi-intensiver Produktionssysteme in Milchvieh-/Futterbauregionen Norddeutschlands. *Berichte über Landwirtschaft*, 75, 586-603.

TAUBE, F.; WACHENDORF, M., 2001. The nitrogen project: a system approach to optimize nitrogen use efficiency on the dairy farm. *Proceedings of American Forage and Grassland Council Conference*, **10**, 223-228.

TILMAN, D.; WEDIN, D.; KNOPS, J., 1996. Productivity and sustainability influenced by biodiversity in grassland ecosystems. *Nature*, **379**, 718-720.

TROTT, H.; WACHENDORF, M.; INGWERSEN, B.; TAUBE, F., 2004. Performance and environmental effects of forage production on sandy soils. I. Impact of defoliation system and nitrogen input on performance and N balance of grassland. *Grass and Forage Science*, **59**, 41-55.

TURNER, B.L.; HAYGARTH, P.M., 2001. Phosphorus solubilization in rewetted soils. *Nature*, **422**, 258.

TYSON, K.C.; ROBERTS, D.H.; CLEMENT, C.R.; GARWOOD, E.A., 1990. Comparison of crop yields and soil conditions during 30 years under annual tillage or grazed pasture. *Journal of Agricultural Science, Cambridge*, **115**, 29-40.

VERTÈS, F.; ABIVEN, S.; LOISEAU, P., 2003. Effects of grassland cultivation and ley-arable rotations an soil quality. In: *Grassland resowing and grass-arable crop rotations – consequences for performance and environment*, Report **2**, 27-40. Eds. J.G. CONIJN, F. TAUBE. Second workshop of the EGF-Working Group 'Grassland Resowing and Grass-arable Rotations'. Plant Research International B.V.. Kiel (Germany). 27-28 February, 2003.

WACHENDORF, M.; BÜCHTER, M.; TROTT, H.; TAUBE, F., 2004. Performance and environmental effects of forage production on sandy soils. II. Impact of defoliation system and nitrogen input on nitrate leaching losses. *Grass and Forage Science*, **59**, 56-68.

WACHENDORF, M.; TAUBE, F., 2005. Abiotic resource efficiency of grassland production systems in north-west Europe. *XX International Grassland Congress: Offered papers*, 755. Eds. F.P. O`MARA, R.J. WILKINS, L. `t MANNETJE, D.K. LOVETT, P.A.M. ROGERS, T.M. BOLAND T.M.. Dublin (Ireland).

HACIA UNA PRODUCCIÓN INTENSIVA SOSTENIBLE DE LECHE DE VACUNO EN EUROPA

RESUMEN

El aumento de la producción de los pastos se ha conseguido con costes ambientales considerables, incluidas la pérdida de biodiversidad, de muchos hábitats de vida silvestre y de paisaje. Desde la década de 1980, los legisladores de muchos países europeos requieren que los investigadores dirijan ciertos aspectos de una producción forrajera sostenible. Las explotaciones intensivas de producción de leche de vacuno de muchos países europeos tienen dificultades para conseguirlo, siendo el exceso y la pérdida de nitrógeno un asunto importante en grandes áreas del norte de la Europa continental, en las que predominan los suelos arenosos. Resultados de estudios detallados en las fincas experimentales de Karkendamm y De Marke (Alemania) muestran la situación actual del nitrógeno en la producción de leche con base en pastos de esta zona e identifican problemas en los sistemas de producción que deberían ser resueltos en el futuro. Simulaciones con el Modelo Integrado de Producción de Leche muestran los efectos a largo plazo de cambios tecnológicos e indican soluciones al problema actual. El cultivo y la renovación de praderas son, entre otros, factores importantes que determinan la producción de forrajes para las vacas de leche. Una revisión bibliográfica sobre estos factores indica que faltan conocimientos sobre muchos aspectos pero indica también que la aplicación de buenas prácticas agrícolas puede reducir los riesgos medioambientales en zonas en que la producción de leche es predominante.

Palabras clave: Manejo de pastos, sostenibilidad, pérdidas de nitrógeno, eficiencia energética.