Title: VII.11 Nitrate leaching from dairy farming. Effect of grassland composition and frequency in crop rotation.

Acronym: NIT-GRASS

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Summary in Danish:

I nitratfølsomme områder med landbrugsproduktion kan økologisk mælkeproduktion udgøre en mulighed for at reducere nitratudvaskningen, hvis N i græsmarkerne udnyttes optimalt. Det overordnede formål med projektet er at optimere N management i økologiske mælkeproduktionssystemer. Arbejdet inkluderer bestemmelse af forfrugtsværdi og nitratudvaskning efter ompløjning af græsmarker i sædskifter med forskellige græsandel og med sammenligning imellem kløvergræs og gødet rajgræs.

1. Summary

In nitrate vulnerable zones with agricultural production organic dairy farming may present an opportunity to reduce nitrate leaching if grassland N is efficiently utilised. The overall objective of the proposed project is to optimise N management in organic dairy farming. The work includes determination of precrop effect and nitrate leaching following ploughing of grassland as affected by grassland frequency in the crop rotation and with comparison between grass-clover and fertilised pure ryegrass.

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3. Introduction

In nitrate sensitive areas with agricultural production an upper limit of 50 mg l^{-1} nitrate in percolation water is recommended. Despite a lower nitrate leaching potential in organic farming compared to conventional farming, organic farming systems are not always below this limit especially in the case of percolation from dairy crop rotations. This is generally caused by the release of N when ploughing out grazed grasslands, and it appears that the total amount of N leached from dairy crop rotations depends of the N utilisation in the pasture phase of the crop rotation (see State of the art).

An experimental area at Research Centre Foulum has been used for investigating residual effects of grass-clover on yield and nitrate leaching in a rotational context. In 1997-99 the effect of grassland history (composition and use) on yield and leaching after ploughing was determined. From this work it was found that grassland history (grass-clover or ryegrass, low or high N-level in feed) only moderately affected the precrop effect and the leaching losses. In contrast management greatly influenced both aspects. When using good management practices (spring ploughing, catch crops and reduced fertiliser application) the release of N from 3-year-old grasslands gave a considerable residual effect for 2 years after ploughing without nitrate concentrations in leachates exceeded the EU Drinking Water Directive upper limit of 50 mg l^{-1} (Eriksen 2001).

In 2000-2002 the effect of pasture age and composition on leaching during the pasture phase of the crop rotation and residual effects on yield and nitrate leaching following ploughing is currently being determined. Preliminary results indicate huge differences in nitrate leaching from older grasslands. While leaching losses from fertilised ryegrass increased dramatically with grassland age it remained at a surprisingly low level from the unfertilised grass-clover (Eriksen and Vinther submitted).

One important remaining question, that traditional short-term experiments cannot answer, is the long-term effect of the frequency of grass in the crop rotation. If soil organic matter (including organic N) is build up during the pasture phase and mineralised following ploughing, what is the importance of e.g. 25 or 75% grass-clover in the rotation for soil organic matter mineralisation and leaching losses? One hypothesis is that the most grass-intensive systems may release unmanageable large amounts of N following ploughing leading to increased nitrate leaching compared to less grass-intensive systems. In the proposed project will be investigated precrop effect and nitrate leaching in crop rotations similar during the last three years, but with widely different grassland frequency in the rotation (25, 38 and 75%). The N utilisation in the three crop rotations will provide information on the long-term effect of the grass frequency in the crop rotation.

The results from the proposed experiment are relevant for planing organic crop rotations, especially in nitrate vulnerable zones. The relevance of this type of information increases with the development towards increasing farm size. On large farms grazing on fields distant to farm buildings is more difficult resulting in a high grassland frequency in the rotation near the farm and a cash-crop rotation furthest away. It is important to determine N utilisation and environmental consequences of this. The results are also relevant for conventional farmers having ryegrass as the experiment includes a comparison between grass-clover and ryegrass.

4. State of the art

Over the last decades, research has greatly improved the opportunities for optimising N utilisation in agriculture. However, recent reviews have pointed out that grassland farming and especially intensive dairy farming still has particularly low N use efficiencies (Davies 2000, Jarvis 2000, Jarvis & Aarts 2000). To avoid the adverse environmental impact of nitrate leaching (Addiscott et al. 1991) it is therefore of considerable importance to improve the N efficiency of dairy farming systems.

In cut grassland systems, N efficiency is usually high and even at fertiliser application rates of up to 400 kg N ha^{-1} little N is left in the field (Prins 1980). Consequently, nitrate leaching following cut grass is often very low (Simmelsgaard 1998). In contrast, intensive grassland management with livestock grazing by e.g. dairy cows has a marked effect on the grassland N cycle and increases the loss potential dramatically (Jarvis 2000). This is because ruminants excrete 75-95% of their N-intake (Whitehead 1995) and the main part of this is deposited directly in the field during grazing. Thus, a considerable build-up of N takes place in grazed grassland the extent of which depends on fertilisation, feeding of dairy cows, stocking density, time of grazing and the botanical composition of the sward (Cuttle & Scholefield 1995). Furthermore, the age of the pasture is important since a new equilibrium is reached after a number of years, whereupon an N surplus is lost by leaching. When comparing older and newly reseeded pastures nitrate leaching losses were 50% lower in the newly reseeded fields compared to the permanent pasture, as average of the first five years after reseeding (Scholefield et al., 1993). There is uncertainty of when the equilibrium is reached, but Johnston et al. (1994) found N accumulation reached a maximum in 3rd year grass-clover in a system without grazing.

As a consequence of the above, ploughing of grassland is followed by a large increase in the mineralisation of N that often exceeds the need of the subsequent arable crop (Francis 1995, Eriksen et al. 1999). Depending on sward type and management in both the grassland and the arable phase of the rotation, this may result in large amounts of nitrate being leached. Although organic farming generally has a lower risk of nitrate leaching than conventional farming systems it is clear that careful management during the ploughing out phase is required (Goulding 2000, Hansen et al. 2001, Haas et al. 2001, Stockdale et al. 2001).

It is well-known that ploughing in late winter or spring (Francis et al. 1992, Djurhuus & Olsen 1997, Raupp et al. 1991) and the use of efficient catch crops after ploughing (Köpke 1995, Francis

1995) are ‘good management practices’ for decreasing nitrate leaching losses from grass swards. Therefore objectives of this work are to quantify the residual effect of different grassland systems on plant production and nitrate leaching following ploughing of the sward in a crop rotation where good management practices are adopted regarding time of ploughing and catch crop use.

5. Objectives and expected achievements

The objective of the project is to determine the importance of the grassland composition and frequency in the crop rotation for residual effects on yield and nitrate leaching during grazing and following ploughing in order to:

- increase the total N use efficiency of the crop rotation and reduce N leaching losses from dairy crop rotations
- suggest specific changes to management and rotation, that may be carried out in e.g. nitrate vulnerable zones within the short term, and
- establish a scientific sound basis for giving advise on these matters in both organic and conventional farming.

6. Methods

Description of experimental area

The experimental area in Foulum for investigating residual effects of grassland offers a unique opportunity to carry out the proposed project. Over the last 8 years three crop rotations has been build up with different frequency of grazed grassland (Table 1) including both unfertilised grass-clover and fertilised pure ryegrass. The proposal is to re-establish grass-clover and ryegrass in 2003 followed by grazing in 2004. In 2005 grasslands similar managed during the last three years (2002-2004) but with widely different grassland frequency in the rotation are ploughed out. In these crop rotations during 1997-2004 grazed grassland has been present 2, 3 and 6 times equivalent to 25, 38 and 75% of the crop rotation. Thus, the long-term effect of composition and frequency of grasslands can be studied.

The three crop rotations are present in a block design with four replicates. During grassland periods, dairy cows always graze the plots. Management in the field has followed organic farming practices except for fertilisation of pure ryegrass.

Within the block design, plots of grass-clover and pure ryegrass, that has been cut until 2001 are present in two replicates. Those are equivalent to crop rotation 3 (Table 1) just without grazing.

Table 1: Crop rotations at the experimental area in Foulum for investigating residual effects of grassland. In brackets is indicated the proportion of grassland in the rotation during 1997-2004.

Year	Rotation 1 (25%)	Rotation 2 (38%)	Rotation 3 (75%)
1994	1st year grass	1st year grass	1st year grass
1995	2nd year grass	2nd year grass	2nd year grass
1996	3rd year grass	3rd year grass	3rd year grass
1997	**Barley**	**Barley**	**4th year grass**
1998	**Wheat**	**Wheat**	**5th year grass**
1999	**Barley**	**Barley**	**6th year grass**
2000	**Barley**	**1st year grass**	**7th year grass**
2001	**1st year grass**	**2nd year grass**	**8th year grass**
2002	**Wheat**	**Wheat**	**Wheat**
2003	**Cereal**	**Cereal**	**Cereal**
2004	**1st year grass**	**1st year grass**	**1st year grass**
2005	Barley	Barley	Barley

Task 1: Determination of precrop effects of grazed grassland rotations

In the spring 2005 the combinations of grassland composition (grass-clover and ryegrass) and frequency (25, 38 and 75% grassland) are ploughed and within each of the four replicates in the block design are established four plots of 12 by 12 m with barley. The barley has ryegrass undersown as a catch crop. To determine precrop effects of N an adjacent reference area without grassland history and with increasing mineral fertiliser N application is established for comparison of yields. To quantify other precrop effects than N and the yield potential for cereals following grassland, cattle slurry is applied to some of the grassland plots at ploughing. As a reference to cut grassland systems, also the cut plots are ploughed. Prior to ploughing of grasslands quantity and chemical composition of above- and belowground plant material is determined as described by Eriksen (2001). During the growth season and at harvest yield and nutrient uptake in all plots is determined.

Task 2: Determination of nitrate leaching

In each of the 12 x 12 m plots are installed three ceramic suction cups at a depth of 1 m and 2 m apart, and every two weeks samples of soil water are collected by applying suction. The accumulated nitrate leaching is calculated after modelling the water balance (Eriksen et al. 1999). This method has been identified as the best practicable method for freely drained, structureless soils (Goulding 2000), which makes it suitable for this soil type. Nitrate leaching will be determined in the year of grassland establishment, during grazing and following ploughing for the different combinations of grassland composition (grass-clover and ryegrass); frequency (25, 38 and 75% of crop rotation) and management following ploughing (4 levels of supplementary fertiliser).

Task 3: Optimising the N cycle of organic dairy farms

At the end of the project all the data that has been collected from the experimental area since establishment of the different grasslands in 1994 will be included in a summarising exercise. This includes N-uptake and nitrate leaching effects from the arable and grassland phase of the crop rotation caused by differences in grassland history, age and frequency – all of which has been combined with unfertilised grass-clover and fertilised ryegrass. Furthermore, N_2-fixation and denitrification has occasionally been determined as well as the N-balance of grazing cows. All this information will be used for constructing crop rotation N-balances and make simple scenarios for the effects of different crop combinations/frequencies. The effect of different management on the experimental area will be related to investigations from practical farms where the overall balance are known and to the results of the model exercises going on in other DARCOF projects. Such simple calculations based directly on experimental results are notoriously useful in the advice of farmers.

Deliverables:

D1 Paper on precrop effects of combinations of grass-clover/ryegrass and different frequencies of grassland in the rotation submitted for international reviewed journal.

D2 Paper on nitrate leaching from different grassland rotations submitted for international reviewed journal.

D3 Paper on nitrogen management in dairy farming systems published in farmers magazine.

D4 Paper on environmental consequences of ploughing different grasslands published in farmers magazine.

Milestones:

M1 The effect of grassland composition and frequency in crop rotations on precrop effects following ploughing has been determined.

M2 The environmental consequences of grassland composition and frequency in the rotation has been determined.

7. Implementation and time schedule

The project starts in 2003, when grasslands are established as undersown in a cereal followed by grazing in 2004. In 2005 grasslands are ploughed. Task 1 (precrop effects) runs in 2005, Task 2 (nitrate leaching) runs from establishment in 2003 until the end of drainage in April 2006 and Task 3 (optimising the N cycle) is continuously developed through the whole project. Deliverables and Milestones will be fulfilled at the end of the project in Jan-May in 2006.

8. Collaborative partners

The project has a life of its own, but it is also an integrated part of other activities in the DARCOF programme and in international programmes. This includes:

- DARCOF project VII.12 will intensively be using the experimental area for detailed studies on leaching of dissolved organic carbon, denitrification and simulation using the DAISY model. The two projects will work in close collaboration experimentally and in the interpretation of data (Contact: Ole H. Jacobsen, DIAS).
- DARCOF project VII.16 will be using the experimental area in communication of results from organic farming research to practical farming (Contact: Jørgen E. Olesen, DIAS).
- DARCOF project I.4 uses the area in research for increased quality of wheat for breadmaking (Contact: Bent T. Christensen, DIAS).
- DARCOF project I.13 uses the area for determination of N_2-fixation of grass-clover and denitrification from grazed grassland (Contact: Per Ambus, RISØ).
- DARCOF project I.3 will be using data from the experimental area for modelling N cycling in organic farming systems (Contact: Jørgen E. Olesen, DIAS).
- The EU-project "Greenhouse Gas Mitigation for Organic and Conventional Dairy Production (MIDAIR)" will be using the two grassland types present in a block design on the area (Contact: Søren O. Petersen, DIAS).
- The project leader is involved in collaboration with a range of European partners through the EU-COST-action 627 "Carbon Storage in European Grasslands".

The results from other projects are continuously being exchanged and this synergy of more projects and many results from the same system improves the opportunity of reaching the objectives of the present project.

9. Budget (1000 kr)

	2002	2003	2004	2005	2006	Total
Months (scientific)	0	0.25	0.25	6	2	8.5
Months (technical)	0	0.5	2	4	2	8.5
Salary (scientific)		11	12	296	104	423
Salary (technical)		14	59	136	69	279
Operation– equipment						
Operation - other		6	28	69	29	132
Overhead		6	20	100	41	167
Total		37	118	602	243	1,000

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