Soil Nitrogen: research and extension

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Driebergen, The Netherlands

LOUIS BOLK INSTITUUT

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12.30 – 13.00	Final remarks and closure.

About the speakers

Valentini Pappa

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Valentini Pappa is currently working at SAC Scottish Agricultural College (UK).

Julia Cooper

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Julia Cooper is a soil scientist working as a Research Associate on the QualityLowInputFood Project at Newcastle University (UK). The goal of her research is to improve the efficiency of agricultural production systems so that maximal conservation of C and N within the soil and the harvested crop can be achieved. Her area of specialization is soil C and N dynamics and she has experience in comparative studies involving compost, manure and NPK fertilizer. She has also studied laboratory indices of N availability and field measures of net N mineralization. She is used to a variety of approaches to study soil C and N dynamics including molecular techniques, standard biochemical methods, field scale studies and modelling.

Ir. Gerard Ros

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Gerard Ros is working at Wageningen University (NL), Soil Quality Department in the project "A novel method in agricultural nitrogen management: unraveling the mystery of natural N release in soils tot the benefit of farming and environment."

Dr. Daniel Neuhoff

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Daniel Neuhoff is agronomist, researcher and lecturer at the Institute of Organic Agriculture (D).

He has coordinated the interdisciplinary DFG funded research group ‚Optimising Strategies in OA' and the EU funded project 'Strategies of Weed Control in OF'. Research activities include /inter alia/ weed control in organic crop production, copper replacement using plant extracts against late blight, wire worm control in potatoes and organic sainfoin production.**

Kristian Thorup-Kristensen

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Kristian Thorup-Kristensen is head of the Research group for Vegetable Production, Institute of Horticulture, University of Aarhus. He has been working mainly on sustainable management of nitrogen in vegetable production systems, mainly organic production. Topics have been crop root growth and N uptake, catch crops, green manure crops and modeling of nitrogen dynamics in crop rotations.

Ir. Geert-Jan van der Burgt

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Geert-Jan van der Burgt is working at the Soil & Plant Department, Louis Bolk Instituut (NL). He is mainly working on long-term soil fertility and modelling of nitrogen dynamics. He is engaged in the development of the NDICEA nitrogen model, in both scientific and practical aspects.

Marina Azzaroli Bleken

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Marina Azzaroli Bleken is working for the Norwegian University of Life Sciences. She has collaborated for many years to an interdisciplinary group (from microbiological and physical soil processes to economics) researching agronomic and policy tools to improve the environmental performance of Norwegian agriculture within an economically viable context. Her major contributions to this group are by mean of dynamic plant modelling and through studies of N cycling and dissipation from large scale systems. For these studies she was invited speaker at the opening plenum session of the 1999 Annual Meeting of the Ecological Society of America, Spokane. Recently Bleken led a review study of published farm N balances, which provides empirical evidences that the ongoing segregation of animal from plant production exacerbates the global N problem. She is responsible for the plant modelling group of the research project "Ecology and Economy of Agriculture in a Changing Climate" (EACC: http://www.umb.no/?avd=54)

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Ir. Marleen Zanen

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Marleen Zanen is working at the Soil & Plant department, Louis Bolk Instituut (NL). She is working in soil fertility and manure management projects, focussing on long-term soil fertility and short-term in crease of nitrogen use efficiency at crop and rotation level.

Ir. Jan de Wit

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Jan de Wit is working at the animal department, Louis Bolk Instituut (NL). As a senior livestock production specialist, he is mainly working on (both economic and ecological) crop-livestock interactions, including the cooperation between specialized arable and livestock farms in the so-called Partner Farm concept.

Robin Walker

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Robin Walker is currently working in the Crop & Soil Systems Research Group of SAC Scottish Agricultural College (UK), where he is the manager of the Aberdeen based long-term organic crop rotation experiment which was established in 1991. This experiment is investigating the long-term sustainability of four organic crop rotations in terms of economic yield, soil and crop nutrients and aspects of biodiversity. Other linked work is investigating C and N cycling within low input agricultural systems, as well as issues relating to energy balance / LCA.

Introduction: nitrogen's degrees of freedom

G.J.H.M. van der Burgt

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Nitrogen is an important and in many cases yield limiting nutrient. In case of leaching, a valuable nutrient is lost and an environmental problem is created. Much research has been focussed on nitrogen in agricultural ecosystems, and much research will probably follow.

In general, looking at nitrogen, some principal points of view should be kept in mind.

First: at which level are we considering the nitrogen question? Root-soil; plant; field; farm; region: at all these integration levels nitrogen will appear in different ways, requiring different strategies in the research.

Second: what time-span are we looking at? In terms of crop production we are used to a time-span of weeks (spinach) or months. In terms of soil fertility and soil organic matter dynamics, ten years should be a minimum period to consider.

Third: what is the spatial aspect of the nitrogen? Here the optimal distribution over the farmer's fields is in view.

Considering these three aspects, a new term is introduced: nitrogen's degrees of freedom. The degree of freedom includes the two dimensions time and space which both can be subdivided in two. The time dimension has the aspect 'timing of application' and the aspect 'delay in availability'. The space dimension has two spatial levels, the 'field level' (freedom to choose the field where you want to use the nitrogen) and the 'root level' (precision farming: exact manure drilling).

This concept of freedom of nitrogen might help us ordering ours thoughts about managing the nitrogen dynamics at field and farm level, as is shown in the following example.

Clover grass or Alfalfa are used to bring nitrogen into the system. The nitrogen in the root nodules has a very low degree of freedom: no spatial freedom and a very limited freedom in time. The only choice (freedom) the farmer has is the timing of ploughing the sward. With the above-ground production the farmer has much more choice.

- Mulching. The nitrogen in the mulching system has a very low degree of freedom: it can only be active in the same field, and it will be active directly after mulching.

- Cutting and direct use as fertilizer on another field. Compared to mulching, the degree of freedom is increased: there is spatial freedom (use in another field), but no freedom in time.

- Cutting and conserving for later use as fertilizer. Now the freedom has further increased because of the time dimension. Looking at the time dimension, the 'time of application' has become free, but the 'delay in availability' is still fixed. Considering the spatial dimension, field choice is free, but precision fertilization is not possible.

- Cutting, drying and making pellets of the above-ground production, to be used as fertilizer. Again the degree of freedom of this nitrogen has increased: this fertilizer could even bu used as a top fertilizer application during the crop growth, so the freedom in time has increased. The 'delay in availability' might also change if the mineralization of these pellets would be faster then the original fresh organic matter. Even precision drilling is possible.

It will be clear that the highest level of freedom is reached by pure mineral fertilizers.

Considering the concept of nitrogen's degrees of freedom, three additional statements are made.

First, there are indeed possibilities for farmers to increase the nitrogen degree of freedom of certain in-farm products. The clover grass above is only an example. What to think about green manures, crop residues? What to think about biodigestion of farm residues, increasing the degree of freedom of the nitrogen inside?

Second, there will be a strong correlation between the overall or average degree of freedom of nitrogen and the soil fertility and manure strategy on a farm. If a farmer is working in a system with a general low degree of freedom of nitrogen, the management tools he can use are mainly at the level of rotation and crop choice. If the system is characterized by a high degree of freedom of nitrogen, fertilizer strategy will be mainly focussing on crop level.

Third, it is not said that a high degree of freedom for nitrogen is the most required situation. This very depends on the choices a farmer makes. Also, a high degree of freedom of nitrogen might, if not used correctly, increase the risk of nitrogen leaching or increase crop health and crop quality problems.

So far, the concept of nitrogen's degrees of freedom is qualitative. It is possible to elaborate this concept into a more quantitative approach. For now, the qualitative approach is sufficient to have a new look at nitrogen dynamics at field and farm level.

Intercrops and N Use Efficiency in Low Input Agricultural Systems

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Modern European intercropping methods were largely developed for organic agriculture but they also have the potential to improve the environmental performance of conventional systems. Transfer of nitrogen (N) from undersown clover to the accompanying spring cereals has been demonstrated (Rees *et al.*, 2006), but the extent to which this contributes to increased N use efficiency within a system is poorly understood. A drained-plot experiment at Edinburgh (55.9°N, 3.2°W), Scotland was used. This experimental consists of 12 hydrologically-isolated plots that have been used previously for nitrate leaching studies. The plots had been fallow for the past three years. The soil is a sandy loam (Eutric Cambisol, Macmerry Series) developed from partially sorted glacial till. In Aberdeen (57.2°N, 2.2°W) the plots were established on a sandy loam (Leptic Podzol, Countesswells Series) in a field which had previously been under grass/clover. The treatments were a barley monocrop, and intercrops of barley with either white clover, pea cv. *Zero4* or pea cv. *Nitouche*, arranged in three randomised blocks.

The objectives of the experiment were to: 1) determine whether there was any yield benefit of intercrops compared with their associated monocrops; 2) investigate the effects of intercrops of different legume species and varieties on nitrous oxide (N_2O) emissions and nitrate (NO_3) leaching from cropping systems. No manure, fertiliser, herbicide or other agrochemicals were applied to the plots. N_2O fluxes were measured at intervals of between one and four weeks by the static flux method and gas chromatography. NO_3 concentrations in the drainage water samples were determined by continuous flow analysis. Grain yields were calculated using values obtained from combine harvesting. The plots remained fallow over winter and oats were grown in all plots in the following year.

The total barley yield of the barley/clover treatment was significantly greater than the barley/pea and barley monocrop at the Edinburgh site. Two out of the three intercrops showed greater N_2O loss than the barley monocrops, and this differed between intercropped species/variety. The two varieties of peas showed large differences in N_2O losses at the Edinburgh site. Intercrops also contributed to varying reductions in the amount of N leached from the plots with large differences between the barley/clover and barley/pea treatments.

Intercropping can result in significantly higher biomass production and nutrient accumulation in the crop. However, N_2O emissions from the legume intercrops were greater than those from the barley monocrop, and NO_3 leaching from the intercrop containing pea cv. *Nitouche* was lower than from the other intercrop treatments. The underlying mechanisms driving these losses are unclear, although they may be linked to differential rates of root growth and turnover in the monocropped and intercropped treatments. This experiment demonstrates the need to take account of the overall N balance when assessing the environmental impact of farming systems.

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Soil tests and their value as indices of N availability to crops

Dr. Julia Cooper, Nafferton Ecological Farming Group, Newcastle University, UK

A realistic estimate of N mineralized from soil organic matter is essential for determining the rate of N fertilizer application required to optimize crop yield and quality and to minimize adverse impacts of excessive N on the environment. (Sharifi et al. 2007)

Why do we need to predict or estimate soil N availability to crops?
Nitrogen is the nutrient most often limiting crop yields, especially in organic systems (Kirchmann et al. 2007). Recommended rates of N application do not usually account for the N supplied by the soil organic matter, although reductions in rates are sometimes advised following the plough-down of an N-rich crop, or to compensate for N in manure applied immediately before crop planting. Since crop yields on organic farms depend largely on mineralization of N from organic matter pools, it is especially important in these systems to have an estimate of N supply from these pools.

What controls N supply from soil organic matter?
N supply to the growing crop in the field is controlled by:

1. N mineralization potential - This is affected by the total amount of N available for mineralization, as well as the soil type, especially its sand, silt and clay content, and the soil's biological capacity to mineralize organic N.
2. Soil temperature and moisture - These two environmental factors are usually assumed to affect the rate of N mineralization.

Within a climatic region where temperature and moisture conditions do not vary dramatically, the soil's N mineralization potential is the main factor causing differences in crop N supply between sites. If N mineralization is to be predicted across climatic regions, models are used that include factors to moderate N mineralization rates due to environmental factors. This session will focus on the range of laboratory tests that can be related to soil N mineralization potential. These tests are called indices of N availability.

Types of indices of N availability
Laboratory tests of soil N availability can be divided into three broad categories:

1. **Biological** indices - These are laboratory tests in which the soil is maintained in a biologically active state, and N mineralized during a set period of time is measured. These biological indices include the Stanford and Smith (1972) leaching tube method, often considered the "gold standard" of N mineralization estimates; anaerobic incubation, in which soils are incubated in test tubes while saturated with water and ammonium-N measured (Keeney 1982); and CO_2-evolution after re-wetting (Haney et al. 2001).
2. **Chemical** indices - These are laboratory tests used to provide an instantaneous direct or indirect measure of one of the pools of soil N. They include: direct extraction of NO_3^--N and NH_4^+-N with 2 M potassium chloride (Keeney 1982); extraction of NH_4^+-N with hot KCl (Sharifi et al. 2007); the Illinois Soil Nitrogen Test (ISNT) (Khan et al. 2001) which provides a measure of amino sugar N; and extraction of the soil with 0.01 M $NaHCO_3$ and reading the absorbance of the extract at 200 or 260 nm (Hong et al. 1990; Sharifi et al. 2007). Measures of the soil's total C and N content (by dry combustion) and biomass C and N (by chloroform fumigation extraction) have also been related to N mineralization potential (Carter and MacLeod 1987).
3. **Physical** indices - While most energy has been devoted to searching for a chemical index of soil N mineralization potential, some measures of physical components of the soil may also be useful as predictors. Soil particle size e.g. sand, silt and/or clay content, may be included with a chemical index to provide a better predictor of soil N mineralization potential. Particulate organic matter C or N (POMC or POMN) (Sharifi et al. 2007) and light fraction organic C or N (LFOC or LFON) can also be related to N mineralization potential.

Assessing laboratory indices as predictors of N mineralization potential
Values obtained for the laboratory indices described above, have been related to N mineralization potential estimated using the Stanford and Smith method. Better relationships are sometimes obtained when researchers relate laboratory indices of N mineralization with in-field

measurements of N availability, including plant available nitrogen (PAN) (Zebarth et al. 2005) and the resin-core technique (Hatch et al. 1998). A simple index that has shown promise recently is the $NaHCO_3$ extract-absorbance test (Sharifi et al. 2007).

Practical applications of laboratory indices of N availability

Predictions using existing decision support tools could be improved if the soil organic N pool could be subdivided into pools of different qualities with different availabilities. Laboratory indices could be used to directly represent these pools, or index measures could be converted to estimated values for these pools, using pedotransfer functions (Heumann et al. 2003). Laboratory indices may also be used to differentiate among sites with similar total N contents that respond differently to added N fertilizer. These indices may also be useful in crop rotation and management experiments, to differentiate among treatments that affect soil N supply. It is important to understand exactly what each index is measuring, when choosing a laboratory index of soil N availability for one of these purposes.

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DON as an instrument for nitrogen mineralization prediction

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Intensive agricultural production in the last century has resulted in high N losses to the environment, which at present forms a major threat for the quality of drinking water. Increasing strict legislation and growing concern for the environmental impact of agriculture urge farmers to use crop nutrients and fertilizers more judiciously. However, the development of a sustainable N management is hampered by the absence of accurate predictions of the amount of N available for crop growth during a growing season. This amount consists of 1) the amount of N_{min} in the soil present at the beginning plus 2) the amount of N that is mineralized from (soil) organic matter during the growing season. Current fertilization recommendations for arable soils are primarily based on mineral N present and for several crops a rough estimate of the mineralization of soil organic matter is included. More accurate quantification of this second pool enables precise matching of the fertilizer N rate to crop N demand, thereby minimizing N losses to the environment.

So far mineralization can be predicted from incubation studies or by models. Incubation studies are time-consuming and therefore unaffordable for farmers. Models are hard to use by farmers, even if they are simple (Janssen, 1984; Yang et al., 2000) and are not highly soil specific. This study contributes to the identification of an alternative, reliable indicator for crop available N. Incubation studies suggest that dissolved organic nitrogen (DON) might be a good indicator for the amount of nitrogen that will mineralize during the growing season (Groot et al., 1995; Bregliani et al., 2006). This is in line with other studies (Appel et al., 1998; Mengel et al., 1999; Murphy et al., 2000; Matsumoto et al., 2004). However, the exact role of DON in the mineralization process and its dependence to agricultural management, soil texture and environmental conditions are still unknown. On the one hand, the development of an integrated approach is hampered by lack of standard methods (Haynes, 2005; Jones et al., 2006), and the results presented in literature are hardly comparable. On the other hand, environmental and soil factors affecting spatial and temporal variability of DON interact at the same time (Zsolnay, 2003).

This contribution consists primarily of a critical analysis of literature regarding DON and its controlling factors as land-use, soil characteristics, environmental controls and the used methodology. We introduce the statistical technique of meta-analysis to deal with the existing differences in methodological approaches between studies. Meta-analysis may provide a quantitative statistical mean of integrating independent results and can be used to identify aspects of experimental design that contribute to variation among studies. Results of this meta-analysis will be presented on the seminar.

In addition, we present results of a review of the role of DON in the mineralization process. Although there are major uncertainties about its exact role, many papers observed high and positive relations between DON and potential mineralization (Groot et al., 1995; Appel et al., 1998; Mengel et al., 1999; Wang et al., 2001; Lazanyi et al., 2002; Curtin et al., 2006). This suggests that DON may be a reliable indicator of plant available N during a growing season. However, until now its role in the mineralization process is never quantified. Its application in common agricultural practice will reduce the N fertilizer rate without reduction in crop yield and quality. It thereby contributes to reduction of N losses to the environment. In contrast to today's varying practices for predicting N release, this method seems applicable to all agricultural soils, whether they are for arable, vegetable or grassland farming. It makes acceptance among farmers as well as the embedding in commercial fertilizer recommendation systems much easier. In addition, more frequent analyses during crop growth allows for adjustment of N fertilization to fluctuation in climatic conditions during the growing season.

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Nitrogen management in Organic Farming: Challenges and threats for vegetable production

Daniel Neuhoff, Institute of Organic Agriculture, University of Bonn

One key element of certified organic crop production consists in the prohibition to use mineral nitrogen fertilisers. Consequently nitrogen supply is often the limiting factor for yields. This abstract shortly discusses the background, why mineral nitrogen fertilisers are not allowed in Organic Farming (OF), before outlining and critically discussing some current organic management practices. The contribution will be completed by a draft proposal, how fertility management could develop without compromising the principles of OF.

The complete renunciation of mineral N-fertilisers in OF is mainly justified with ecological and crop - physiological reasons.

First and foremost the synthesis of mineral nitrogen is an energy consuming process metaphorically spoken the fertilisation of the soil with processed oil (e.g. in reference year 2005/2006: Netherlands = 138 kg N ha^{-1}, Germany = 105 kg N ha^{-1}, Italy = 41 kg N ha^{-1}) averaged over the total agricultural surface including pastures and fallows, IVA 2007).

At the same time current fertilisation practices may result in significant nitrogen losses and subsequent pollution via nitrate leaching (contamination of groundwater) and denitrification (greenhouse effect).

On the crop level nitrogen fertilisation may indirectly result, however not necessarily, in increased susceptibility to some pest and diseases and significant changes in crop metabolism partially linked with impacts on food quality, e.g. nitrate contamination.

Nota bene that most negative impacts known of mineral nitrogen fertilisers are predominantly a function of the amount of nitrogen given.

To increase and maintain soil fertility organic systems have mainly to rely on legume cropping combined with manure production and application. The amount of nitrogen fixed within a crop rotation is therefore a base factor for crop productivity. All other management practices including manuring mainly have to focus on minimizing nitrogen losses and on optimizing the spatial and seasonal availability. This approach is (or rather should be paradigmatic) for organic systems.

The use of farm yard manure (FYM) has beneficial effects on both crop productivity and soil carbon balance. Within the QLIF project we compared the impact of kind (mineral vs. organic) and intensity (85 and 170 kg N ha^{-1} resp.) of fertilisation on yield and quality of lettuce including also hygienic parameters (Rattler et al. 2005). Minerally fertilised lettuce showed a quicker development resulting on average in a reduced growing period of up to 11 days, when compared with FYM. On contrast, the impact of the different fertiliser types on yield was not significant, probably due to the low nitrogen requirements of lettuce and sufficient nitrogen release from the soil.

The amount of secondary metabolites including lutein, beta-carotene and polyphenols, was significantly higher in minerally compared with organically fertilised lettuce suggesting an increased synthesis of these compounds with abundant presence of nitrogen in the crop.

Nitrate content, a key quality parameter of lettuce, was significantly lower in lettuce grown with FYM compared with mineral fertilisers. Cell density was significantly higher in organically compared with minerally fertilised lettuce.

Former experiments with increased FYM application to organic potatoes, partially in comparison with mineral nitrogen fertilisation, confirm these findings. The nitrogen effect of FYM was comparatively low, while the overall mineral supply was positively affected by manuring (Neuhoff & Köpke 2002).

Economically interesting organic vegetable yields require high nitrogen supply. Manuring and legume cropping may be insufficient to obtain high yields. Some nitrogen fertilisers such as fermented molasses or coarse meal (e.g. of faba beans) are allowed, if the necessity has been proved. Their application, if abundant, i.e. satisfying the nitrogen requirement of a crop to a substantial proportion, is opposed to the principles of OF.

These fertilisers are either transformed mineral nitrogen (e.g. fermented molasses derived from conventional sugar beet production) or may require excessive land use if for example producing faba beans for coarse meal. Energy balances for this type of organic nitrogen fertiliser have not yet been calculated as far as known. Impacts of N rich organic fertilisers on crop quality and nitrate leaching, if considered relevant, still have to be assessed.

From the agronomic point of view the decisive disadvantage of this category of fertilisers is their negative impact on the soil carbon balance in vegetable crop rotations, if not accompanied by a sustainable management of soil organic matter.

A way out of the dilemma. i.e., that economic benefits compromise the principles of OF, is possible, if a lower yield level in OF is accepted. The use of additional organic fertilisers should be in accordance with the overall humus management and mainly serve to adjust temporary nitrogen deficiencies. Limiting the use of organic fertilisers by defining maximum amounts, while at the same time promoting adequate carbon supply, is an option to ensure sustainable organic vegetable growing.

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Significance of crop root growth for N dynamics in organic rotations, experimental results and simulation modeling

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It is often said that a healthy soil and well developed root systems are very important for successful organic crop production. However, few experiments have been made to test this and increase our understanding of crop root growth and its importance. We have been working now for several years with the significance of crop root growth for soil N utilization. We have studied root growth of a number of arable crops, vegetable crops, and fertility building crops. We have also studied factors which may affect root growth, and how differences in root growth affect N dynamics and losses from cropping systems. With experiments and model studies we have investigated how this knowledge about crop root growth can be used to design N efficient cropping systems.

The main conclusions from this work are:

- Crop rooting depth is the single most important root parameter controlling the ability of crops to utilize available soil N efficiently.
- Utilization of soil N depends on aboveground factors as well as on roots. If aboveground N demand is low, and N will be left in the soil even if the crop has a very strong and deep root growth.
- Differences in rooting depth vary strongly among crop species. In our studies the variation has been from only 25-30 cm rooting depth for onion to rooting depths exceeding 250 cm for some brassica crops. Among cereal crops we have found roughly twice the rooting depth in winter cereals (c. 200 cm) compared to spring cereals (c. 100 cm). Also among fertility building crops we find large differences [5].
- Differences in rooting depths depend on the rate of rooting depth development and on the duration of growth. Rooting depth development vary among species, we have found rates from 0.2 mm per day degree for onions and leeks to 3 mm per day degree for fodder radish catch crops [1,2]. Even crops with fast root growth need some months to achieve a very deep rooting, but also crops with a medium rate of rooting depth development (0.7 to 1.0 mm per day degree, e.g. cereal crops) can reach substantial rooting depths if they have a long growing season.
- Our studies have shown examples of cultivar effects on root development, and on effects of pre-crops or fertilization levels on root development. However, these effects have always been small compared to the differences among species.
- The main N loss process is leaching loss, i.e. downwards movement of N. Therefore the ability of the roots to “follow the N” to large soil depths is important for designing N efficient cropping systems.
- Deep rooted main crops or fertility building crops should be grown especially where significant leaching has just occurred, as in such situations there is likely to be significant amounts of available N in deep soil layers [1,3,4].
- Nitrogen catch crops and other fertility building crops affect total N supply, but often it is more important that they concentrate available N in the topsoil. Therefore they are especially valuable when grown before shallow rooted main crops [3].
- Agronomic aspects as management of fertility building crops, establishment time, incorporation time, species choice and composition are important tools to improve the effect of fertility building crops.
- These relationships are in theory simple, but in practice they are complicated, as they depend on a number of soil, crop, management, and weather factors. Therefore, simulation models are valuable tools for integrating this knowledge for practical use, as they can simulate the main effects of all these factors at once.

Many crop models have been developed during the last 20-30 years, and several of them can in principle be used for studies and simulations of the effects of catch crops, fertility building crops, crop root growth and crop rotation design in organic farming.

However, there are at least two main problems, making most of the models of limited value for this. First, the models have been developed with for conventional farming. Therefore, there has been too little focus on aspects of crop growth and soil processes which are especially important under low N conditions. Further, there has been very little focus on crop root growth. For a number of reasons, the huge amount of studies done on the agricultural N processes during the last decades includes few studies on the effects of crop root growth. This is reflected in models through lack of focus and data for this.

Based on our root studies, we have developed a root module for the newly developed EUrotate crop model. This module allows more dynamic simulations of roots and their interactions with soil N. We have also worked on improving the ability of this model to simulate crop growth and N dynamics in organic rotations which are often N limited.

At the workshop, experimental results on N husbandry in organic rotations will be shown, with a focus on crop root growth and its significance. Further, our modeling work on these topics will be presented, including a presentation of the main aspects of the model structure we made, and rotation simulations showing how such a model can be used in the attempt to develop better organic crop rotations. Finally, the model will be demonstrated, with a focus on root modeling and on illustrating the significance of the root parameter values used in the model.

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The NDICEA model: a practical instrument to improve nitrogen efficiency

G.J.H.M. van der Burgt, Louis Bolk Instituut.

Introduction

Nitrogen is important in plant nutrition, and under organic conditions it often is the yield limiting factor. According to organic regulations the application of nitrogen is limited, and many of the used manures and other applications are characterized by a slow nitrogen release pattern. Compared to conventional cropping with the use of artificial fertilizers, plant available nitrogen is much more dependent on decomposition of soil organic material. This all makes the management of nitrogen rather complex and multi-factorial. Modelling of the dynamics is of great help to manage crops and soil fertility.

The NDICEA model

NDICEA is an acronym for "Nitrogen Dynamics In Crop rotations in Ecological Agriculture". It is constructed by Wageningen University and further developed by the Louis Bolk Instituut. The objective for this model is to be an instrument for farmers / gardeners and their advisors which helps them to understand nitrogen dynamics of their particular situation, and which can support decisions on manure application, crop choice and crop sequence. Because of this objective, the model is build up in a different way from many other existing nitrogen models.

- The input for the model must be available "at the kitchen table". No unusual soil measurements or other analysis is required: the model can do with agronomic information that is normally available in the head or the administration of the farmer. In short: crop (sequence and yield, time of sowing and harvest); manures applied (type, quantity, time of application, mineral content); green manures (type and timing); soil (choice out of dataset, soil organic matter, soil mineral nitrogen if measured); irrigation (if any).
- The crop sub model is target-oriented. In most nitrogen models, the crop growth is modelled dependant on nitrogen availability and global radiation. In NDICEA the target yield (expected in future, or realized in past) is chosen and the growth and nitrogen uptake is build up from zero (sowing) to target (harvest) according to global radiation and expected nitrogen uptake.

What does the model show?

Although the model performance is good, it is necessary to check it for each situation by measuring several times the inorganic nitrogen status and compare it with the model reconstruction (van der Burgt et al. 2006A). If measurements and simulated level are sufficiently corresponding (Fig. 1), the model can be used as decision support instrument (van der Burgt et al. 2006B).

The first question farmers want to have answered is: is there potentially enough nitrogen to reach the expected yield? This is shown in a three-line graph for each crop (Fig. 2). The red line is the crop uptake, the green one is the plant available nitrogen, the grey one is nitrogen fixation. The uptake line is relatively simple interpolation between zero and target yield. The available line is a complex one: this is the result of nitrogen increase (organic matter decomposition, nitrogen application, deposition, fixation) and decrease (temporary immobilisation, leaching, denitrification, crop uptake). The interpretation of this graph, simply said: as long as the green line stays above the red one, there is enough nitrogen to reach the target (realized or expected) yield.

The second question farmers are interested in is: where do I lose nitrogen? Another graph shows leaching (Fig. 3). Here you can see when (or where) in the crop sequence nitrogen losses occur and to what amount.

With these two graphs in mind the farmer or his advisor can start analysing the situation. Within the model, scenarios can be explored changing the manure strategy, changing the crop sequence or introducing green manure (management at strategic level). If next-year crop seems to have to less nitrogen to reach the expected yield, consequences of an additional or changed nitrogen application can be explored (tactical level). In all these cases the farmer plays an important role: he has the task to judge the 'new' situation and for example give realistic expectations of expected yields.

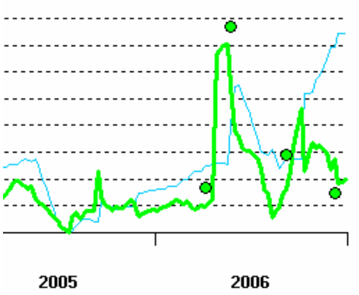

Fig 1. Measured inorganic N (green dots) and simulated level (green line, top soil)

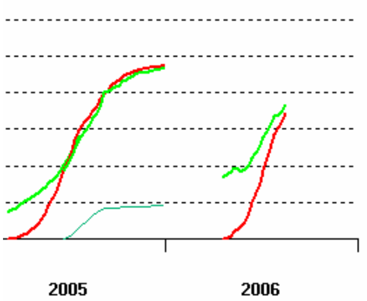

Fig 2. Crop optake (red), available nitrogen (green) and fixation (grey)

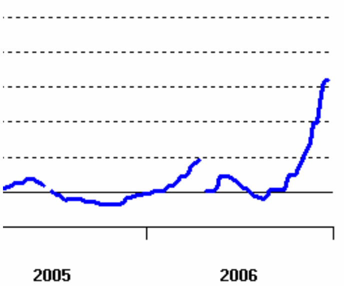

Fig 3. Leaching, cumulative per crop.

Model performance in the scientific community

The model has been described and validated by van der Burgt at al (2006 A) using a German dataset. Kersebaum et al (2007) gives a comparison of the performance of several models on this German dataset, in which the NDICEA model shows a good performance in the prediction of soil inorganic nitrogen. In van der Burgt et al (2006 B) some cases are described how the model is used in contact with farmers. Topp et al. (2006) used NDICEA to analyse a rotational experiment, and the model performance was good with a root means square error of inorganic nitrogen prediction of 11.8 kg ha^{-1}. Within the Louis Bolk Instituut, the model has played important roles in several soil fertility related projects.

Model performance in society

Although the model was build to be used by farmers, the original interface was unattractive. In 2002 the interface was completely reconstructed. Many parameters were hidden, loading of weather data was done via internet and the construction of a field scenario was organized wizard-like. A short manual was written and the model was (and still is) published at www.ndicea.nl .

Although some farmers do use the model, the target that many organic farmers would use this model has turned out to be to far away. Since 2005 the model is used by farm advisors in their contact with (organic) farmers. In 2007 two private farm advisors were offering an NDICEA support service. Also in this year a big farm registration service company (>2000 customers, conventional agriculture) bought the model and integrated it in their software package. This has the big advantage that the agronomic data, needed to run NDICEA, are simply copied out of the existing registration database. This might be the most attractive way for future development of the model: cooperation was farm registration companies instead of a stand-alone internet NDICEA model.

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Closing the plant-animal loop: a prerequisite for organic farming

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Organic farming movements have traditionally aimed at a harmonious balance between animal husbandry and crop production on the farm. We bring scientific evidences that this is a prerequisite to maximize the efficiency of nitrogen use. The use of imported feed increases the total nutrient losses to the environment per litre of milk produced.

Introduction

Imports of external resources that can blow up the production have traditionally been restricted in organic farming, based on the intuition that this would bring the agro-ecosystem in an unbalanced and unstable condition. However, while the ban on easily soluble fertilizer is still widely practiced by organic movements, imports of feed have been largely liberalized. Organic production of cereals for animal consumption in regions without animals is presently suggested as a viable alternative to increase organic production in Norway. Furthermore, it has been suggested that supplementing grass with energy concentrated feed can improve the protein retention by the cattle and thus the N efficiency of dairy production. Also a widespread tendency towards further specialization in agriculture in general challenges organic farming: if specialization and use of off-farm feed improves the nutrient use efficiency in the farm, why not adopting them?

Methods

The nitrogen (N) efficiency of cattle milk production in Europe is used as an example of the consequences of the separation of plant from animal production. Data were collected from published surveys of groups of several commercial farms or of single prototype farms, covering a wide range of environmental conditions (from Northern Italy to Southern Norway) and yield intensity (from 3000 to 13000 l milk $ha^{-1}y^{-1}$). Six surveys regarded organic or integrated farms and fourteen regarded conventional farms. "Soil-less" farms (those that buy more than 50 % of the feed ration) were excluded. Farms with a net sale of plant products were also excluded. Figure 1 illustrates the inputs and outputs of biologically available N related to the dairy farm system, which were estimated in kg N per year and per ha of land of the dairy farm. The produce (P) is the N amount in the net sale of milk and livestock (1 kg N corresponds to ca 200 kg milk or 40 kg animal live weight). The net N amount in purchased feed ($F_{off\text{-}farm}$,) was found by subtracting the sale of farm's crops. The N surplus on the farm (S_{farm}) was calculated as the difference between the total N input into the farm (fertilizer, biological fixation and atmospheric deposition) and the nitrogen in the produce P. On the long run this surplus gives the potential N emission from the farm to the environment. The emission factor $E_{farm} = S_{farm} / P$ is the amount of N (in kg kg^{-1}) that is dissipated from the farm in order to produce 1 kg of N in milk + livestock. Nitrogen is lost ($S_{off\text{-}farm}$) also during the production of imported feed, thus the total emission factor is larger: $E = (S_{farm} + S_{off\text{-}farm}) / P$. See Bleken *et al.* 2005a and 2005b for details.

Results

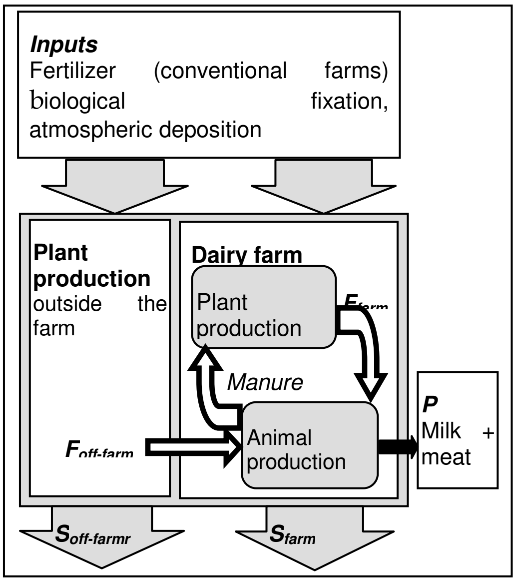

Figure 1. Major nitrogen flows related to dairy a dairy farm. See text for explanation of the acronyms.

The surveys showed that the animal production is enhanced by the use of purchased feed, but it also showed that farms that buy greater amounts of feed compared to the total amount of plants (crops and leys) produced on the farm (F_{farm}) dissipate increasingly greater amounts of N to produce a given amount of milk. If the purchased feed improved the N utilization by the animals, this advantage was not reflected by a lower N emission factor E_{farm}, primarily due to the fact that imported feed increased the load of animal manure, which was used less efficiently. When emission related to purchased feed is included as well, the relationship between the total emission factor E and the use of purchased feed (relative to the farms own crop production) is astonishing: $E = 2.3 + 8.1\ F_{off\text{-}farm} / F_{farm}$, $R^2 = 0.85$.

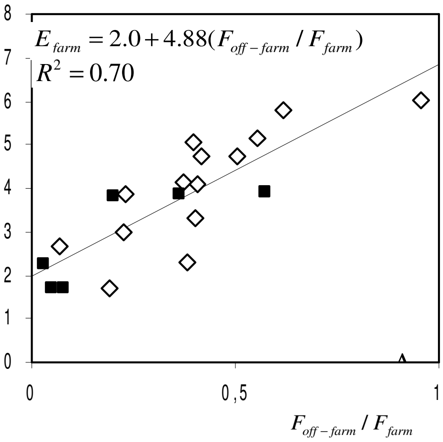

Figure 2. N emission factor from the farm E_{farm} and versus the ratio of the imported feed to the plant production on the farm ($F_{off\text{-}farm} / F_{farm}$). Closed symbols: organic or integrated farms. Open symbols: conventional farms.

There were no significant differences between organic/integrated farms and conventional farms. This indicates that the additional manure N derived from feed imports was not effectively utilized, in spite of no use of chemical N fertilizer in the farms driven organically. This has two negative consequences: directly on the N dissipation from the dairy farm and indirectly by raising the need for other sources of plant available N at the production site of $F_{\text{off-farm}}$.

A closer inspection of the organic farming systems illustrates the significance of alien feed, in doses which are usually considered small or moderate, on the N dissipation (Table 1). The share of alien feed was low, on average ca 5% of the total ration, in the two surveys in Austria and in the Norwegian organic prototype farm. The Danish organic farms and the Welsh organic prototype had a larger use of alien feed, 26 and 36% of the total ration respectively. Within this interval (5 – 36% of the total ration) the emission factor E increased by a factor of ca. 2.6.

Excess manure contributes to phosporus as well as to N eutrophication. On the other side, soils with large export of plant products and no return of animal manure can be depleted of nutrients and organic matter. Thus, it is reasonable to state that the N-pollution problem is only an example of several reasons for re-coupling plant and animal production together on the same territory.

Table 1. Farm's milk + meat produce (P), total animal manure available at the farm (M), ratio bought feed to *total* feed and total N emission factor E (kg N / kg N).

	kg N ha^{-1} y^{-1}		Ratio bought feed / total feed	
	P	M		E
Norway, prototype	17	62	0.03	2.4
Austria, n* = 40	20	72	0.05	2.0
Austria, n = 51	21	74	0.07	2.1
Germany, n = 6	22	79	0.17	4.8
Denmark, n = 14	32	124	0.26	5.5
Wales, prototype	40	144	0.36	6.1

*: number of farms in the survey.

In conclusion, closing the plant-animal loop is a prerequisite for organic farming because it is an effective way of minimizing the N dissipation from dairy production, and legitimates organic dairy farming as more environmentally sound than farming based on imported feed and fertilizers. For more information in Norwegian see Steinshamn *et al.* (2004).

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Rotation experiments with biogas digestion of slurry, cover crops and crop residues: effects on nitrogen dynamics.

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Introduction:

Nitrogen in organic farming:

- The most important growth limiting factor in organic farming systems.
- High losses within the farm cycle (housing, storage, application).
- Organic manures: low synchronization of crop N demand and N release, resulting in low N use efficiencies, promoting the risk of N losses (nitrate leaching, nitrous oxides).
- Green manuring of cover crops or clover/grass-leys: N immobile, site- and time-bound, therefore no reallocation of N, resulting in higher risk of losses during winter time. N surpluses in some rotation segments and N deficits in others. N availability of incorporated biomass much lower than N availability of the same biomass after digestion through animals.

Expectations on biogas digestion:

- Due to N mineralization during the digestion: higher N use efficiency.
- Lower N losses due to nitrate leaching and ammonia volatilization.
- Lower rates of climate gas emissions due to covering the manure stores.
- Supply of power energy, replacing fossil fuels.
- Alternative utilization of the biomass of clover/grass, grassland, cover crops, straw, etc.
- Import of substrates: replacement of mineral nutrients (P, K) exported via sold products.

Material and Methods:

Presentation of the results of two rotation experiments:

- **Biogas in an organic farming system with animal husbandry:** 8-year crop rotation (3 legumes, 5 non-legumes), 70% arable land and 30% grassland, 0.8 LU. Comparison of 5 manuring systems: (i) farmyard manure, (ii) undigested slurry, (iii) digested slurry, (iv) digestion of slurry and crop residues like cover crops and resting straw, (v) like iv, additional digestion of imported substrates at 40 kg N ha^{-1}.
- **Biogas in a stockless organic farming system:** 6-year crop rotation (2 legumes, 4 non-legumes). Comparison of 3 manuring systems: (vi) usual stockless management with mulching clover/grass and incorporation of crop residues like cover crops and straw, (vii) digestion of all crop residues like clover/grass and cover crops and reallocation of nutrients in the effluents of the digester within the same crop rotation, (viii) like vii, additional digestion of imported substrates at 40 kg N ha^{-1}.

Sampling: DM growth of crops and cover crops; cycles of N, P, K; soil mineral N content in spring and autumn; soilborne greenhouse gas emissions (N_2O, CH_4), ammonia volatilization.

Modelling: Nutrient balances including N_2-fixation, life cycle assessment (greenhouse gas balances, balance of the use of fossil fuels, eutrophication and acidification).

Results:

The summarized results obtained in field experiments and by modelling are presented in Table 1. The total amounts of manures as a sum of green manuring and mobile manures were influenced mainly by the purchase of external substrates for digestion. However, the level differed between both trial series. Digestion of crop residues and cover crops influenced in both trial series strongly the amounts of mobile N, ammonia-N and N allocation to legumes (as incorporated crop residues and cover crops) and non-legumes. Also the amounts of C for humus reproduction were influenced strongly through the performed manuring system. N inputs due to N_2 fixation were influenced by manuring (slurry, straw) to cover crops, cover crop management (harvested or not) prior to grain legumes and by the management of the clover/grass-ley (mulched or not), influencing the total N inputs into the respective system.

Table 1: N cycle (amounts of circulating N, mobile N, ammonia N and N applied to legumes respective non-legumes, N inputs via N_2 fixation, ammonia losses; all values in kg N ha^{-1}), soil C supply, yields (t ha^{-1}), soil mineral N content (N_{min}) in November (kg N ha^{-1}) and greenhouse gas balance of the manuring systems performed within both trial series

	Systems with animal husbandry					**Stockless systems**		
variants	**i**	**ii**	**iii**	**iv**	**v**	**vi**	**vii**	**viii**
Total circulating N	157	172	169	173	216	128	126	154
Mobile N	84	90	87	151	193	0	104	132
Ammonia N	18	40	44	76	85	0	43	55
N applied to legumes	45	55	54	14	14	83	10	10
N applied to non-leg.	225	241	239	264	336	150	180	223
Applied organic C	2.5	3.2	3.0	2.1	2.8	3.2	1.4	1.7
DM yields non-leg.	11.8 a	12.3 b	12.5 b	12.9 c	13.3 d	9.3 a	10.5 b	10.0 b
N uptake non-leg.	114 a	124 b	124 b	139 c	149 d	98 a	113 b	106 ab
Nitrate leaching risk	49 b	46 ab	47 ab	42 a	49 b	52 b	43 a	48 ab
Relative greenhouse gas balance (%) [1)]	162	100	68	49	-	100	41	-
N_2 fixation	154	162	159	158	161	113	138	135
Ammonia volatilization	2.5	6.0	7.5	11.1	15.5	0	14.5	19.0

[1)] In the system with animal husbandry relative values compared to ii (undigested slurry); in the stockless system relative values to vi (usual stockless management).

Manuring systems influenced DM and N yields of non-legumes, and had no influence on DM and N yields of legumes. Environmental effects like nitrate leaching risk, greenhouse gas emissions and ammonia volatilization were influenced significantly by digestion of residues.

Conclusions:

- Higher N use efficiency? → Only if the digested slurry was incorporated immediately after spreading, respective if cover crops and the clover/grass-ley was harvested and digested instead of mulching, and the effluents were applicated within the same rotation.
- Lower N losses?
- Nitrate leaching risk: effects only if crop residues like cover crops and clover/grass-ley were removed, digested and reallocated in spring.
- Ammonia volatilization: higher losses after digestion due to higher pH and higher ammonia concentration.
- Lower rates of climate gas emissions due to covering the manure stores? → Yes, mainly due to lowering emissions from stores and the credit for replacing fossil fuels.

- Alternative for utilization of the biomass of clover/grass swards, grassland, cover crops, straw, etc. → win-win situation through the production of power energy and some positive influence on the allocation of nutrients (time and site) within the system.
- Replacement of mineral nutrients like P and K exported via sold products? → Disproportionate, mostly to low replacement of P and a above average replacement of K.

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Effects of manure choice on soil development and short-term nitrogen dynamics

M. Zanen, Louis Bolk Institute

The context of research on sustainable soil management

- Soil degradation due to erosion is a worldwide problem: we run out of soil earlier than we run out of oil! Most serious problems with soil degradation in Africa, Asia and Latin-America: soil erosion is the most visible form of soil degradation. In southern Europe 30 ton/ha is lost while only 1 ton/ha is added: an irreversible process.

- The inconvenient truth about climate change: farmers have to deal with more extreme weather conditions.

- Focus on high yields, expensive labour and technological innovations resulted in heavier machines.

- And within this context farmers are trying to produce good food!

The problem of soil management

- In the Netherlands this leads to soil compaction, loss or inefficient use of minerals (anaerobe conditions), water drainage and retention and yields loss. Nitrogen plays an important role in many of these problems, but it can be questioned if nitrogen is the most important growth limiting factor.

- In the earlier days the relationship between a farmer and his soil was obvious. Attitude was dominated by respect. Step by step farming evolved towards a more industrial and intensive agri-culture. Attitude was dominated by materialism and all actions were focused on maximum yield. The distance between the farmer and his soil became bigger. But, after 50 years of intensive farming, more and more farmers in the Netherlands now experience the consequences of their actions. Input is rising, but yields stay behind.

Towards sustainable soil management

- Our research approach at Louis Bolk Institute can be described as experimental science. Our approach is not based on isolated facts. Our characteristic integral approach is distinctive. We try to investigate soil structure, soil life and rooting in relation to each other. We actively involve farmers in the research. This approach is not only instructive to both farmer and scientist, but it also motivates them to attempt more sustainable soil management.

- So, when working with farmers we always try to have these questions in mind: what do I see? How does it work? And, what can I do about it?

Case: short term N-dynamics – Haverbeke – Preliminary results

- **Introduction** In the Netherlands organic manure is scarce and use of (conventional) minerals is restricted by regulations. Minimizing losses is one of the objectives. More knowledge is needed about alternative fertilisation strategies. The aim of this trial was to assess the effect of seven different manure strategies (vinasse, alfalfa, chicken manure, goat manure, compost, goat manure and vinasse, compost and vinasse) on soil fertility, crop yield, nitrogen losses and soil organic matter content. **Materials and methods** The experiment was conducted at an organic vegetable farm in IJzendijke (Zeeland). The soil was characterized as clay loam (2,7% organic matter, 23% clay, pH-KCL 7,5). The experiment was set up in a randomised complete block design with four replications. Single plot size was 7 x 7 m. The trial started in the autumn of 2003 and lasted till 2007. Compost and goat manure were given in autumn, vinasse, alfalfa and chicken manure were given in early spring before planting. Manure gift was based on N-need depending on the crop rotation (onion, wheat, potato). Per plot mineral N-availability was measured 5 times at 0-

30 cm depth during the growing season, soil structure was rated as a percentage of crumbly, round and angular structures, using a modified method according to Shepherd (2000). Pores in clods were defined as >2 mm diameter and counted on 400 cm^2. Rooting was estimated. Yield was assessed by harvesting a part of the plots. Soil-N flow, nitrogen losses and effects of strategy on soil organic matter content over time were modelled using NDICEA (van der Burgt et al., 2006). **Results** On 'good' clay soils in the Netherlands N mineralization reaches up to 60 kg NO_3/ha, even after three years without manure. However, adding manure can lead to significant higher N amounts (Graph: Nmin potato). In potato these higher N amounts resulted in higher yields as well. However, in onion (2005) Nmin was relatively low with goat manure and compost but yields were as high as with chicken manure or vinasse (Nmin twice as high). In wheat Nmin was hard to measure, but interestingly alfalfa resulted in the same yields as the use of chicken manure. Modelling in NDICEA showed that vinasse, alfalfa and chicken manure lowered the amount of organic matter in the soil, goat manure and compost increased the amount of organic matter over the years. **First conclusions** Different manure types have different effects on soil fertility and yield. Alfalfa seems a promising alternative for chicken manure. Vinasse and chicken manure result in the highest yields, but in the highest losses of nitrogen or unwanted build up of phosphate as well. In compost N-loss is relatively low. Only compost and goat manure enhance organic matter content in the soil. They also seem to enhance earthworm activity and intensify rooting of onions and therefore have a positive effect on soil structure.

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On-farm research to increase N-efficiency of maize silage after ploughing grass clover

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Introduction

Minimizing losses is one of the objectives of organic agriculture. Moreover, organic manure is scarce if organic agriculture will become less reliant on manure and fertilizers of conventional origin. Nitrate concentrations under organic grasslands are typically low, but increase to high levels (up to 150mg/l) after ploughing for grassland renewal or for silage maize/grain production, due to the fast mineralization of organic matter accumulated in the sward and soil (Hassink and Neeteson, 1991). The amount of accumulated organic matter is related to factors such as the age of the sward, form of utilization (grazing>>mowing), level of manure application rate and soil texture (e.g. Velthof and Oenema, 2001).

Methodology

Experiments were conducted on-farm to include relevant agro-ecological conditions, as part of a programme using a participatory farming systems research approach (Collinson, 1999). Layout of the trials was made in close contact between farmers and researcher, farmers' observations were included, results were discussed with wider groups of interested farmers. The experiments consisted of a major part of a field with the following treatments:

A) "standard" practice, i.e. application of 20m3 of slurry early spring, mowing grass (mid May), soil ripping, application of 30 m3 slurry, ploughing and sowing maize (end May);
B) Like A, but with 15 m3 slurry application before ploughing;
C) Like A, but with no slurry application before ploughing;
D) Like A but no slurry at all;
E) Like D but with early soil ripping (end April) to enhance N-availability;
F) Like D but soil ripping already in the beginning of April;
G) Like F but with 20 m3 slurry application before sowing the maize.

The experiments were conducted in 2003 at three farms:

1. On a loamy sandy soil (3.6% OM in 0-20cm) after more than 4 years of grass-clover (alternately mowed and grazed), with all treatments except G.
2. On a weak loamy sandy soil (2.5% OM) after 3 years of lucerne (only mowing). All treatments were included.
3. on a loamy loss (2,6% OM), after three years of arable crops followed by one-year grass-clover (> 50% clover), with A, B, C, D and E as treatments

Mineral N-availability was measured 9 times; maize production was assessed by harvesting three rows of 3 m/plot. Fields were visited regularly and results were discussed with several groups of interested farmers both during the growing season at one of the experiments as well as later in specific meetings. Mineral N-availability in the layer of 0-30 and 30-60cm was modelled by the soil-N flow model NDICEA (Koopmans & Bokhorst, 2002). Results are handicapped by an unfavourable growing season: a hot and dry period from mid June till the end of August after a few weeks with considerable rain (end of May). Consequently, small local variations in soil texture and water tables may have affected the results.

Results

Average net N-output (N harvested + residual N in autumn– available N early spring – N manure) of the ploughed grass clover/ lucerne was calculated on average at 235 kg N/ha, with lucerne being slightly lower but no clear differences between 1 year and older leys.

In table 1 it is shown that earlier soil ripping (E, F and G) gives highly variable production responses, partly related to wet conditions during soil ripping of treatment E. N-losses seem to be enhanced due to higher N-availability while plant uptake is reduced (no grass harvested).

It also shows that early slurry application (C) does not increase maize production while it increases (potential) N losses. A small quantity of slurry (B) before sowing maize increases N losses but it also results in a higher maize production. Higher manure dose (A) reduced average production due to low production of farm 3, which correlated with the observation of crest formation, possibly due to slurry application on a wet soil followed by a dry period.

Table 1: Average results and calculated losses (nitrate leaching and denitrification).

Treatment (n=..)	N-fertilization (kg total N/ha)	Maize production (ton DM/ha)	Measured residual N (kg N /ha)	Model calculated losses during growing season (kg N/ha)
A (3)	172	15,8	72	95
B (3)	120	16,9	86	60
C (3)	69	16,2	70	40
D (3)	0	16,2	57	29
E (3)	0	15,3	69	72
F (2)	0	18,6	71	56
G (1)	38	13,5	55	117

Model testing for individual farms proved predictions were sufficiently good, particularly in the layer of 0-30cm with an average mean root square error of 25 kg and an index of agreement of 0,88. Average differences between calculated and measured mineral N availability are rather small and main differences correlate with unfavourable weather conditions with soil preparation (farm 1, treatment E) or with manure application (farm 3, treatment A), resulting in lower mineralization and/or higher denitrification than model predictions. The participatory on farm research resulted in less adequate recorded weather and field conditions (enhanced by temporary labour constraints of the researchers). But it proved beneficial in a practical evaluation of the treatments, mutual learning and combined action: farmers as well as researchers, seeing the modest effects of the treatments on maize production and high potential N-losses in all treatments, concluded that a new system of maize production should be developed in order to reduce potential N-losses more drastically.

Conclusions

High N-mineralization of grass clover after ploughing renders it difficult to produce silage maize without substantial N-losses. Manure application, particularly early in the growing season, can be reduced as it affects maize production only slightly while it enhances N-losses. Early soil ripping, followed by a bare soil for several weeks until sowing, does not reduce N-losses while production response is variable. Favourable weather conditions around soil preparation seem at least equally important to obtain good production levels.

Participatory on farm research has hampered /complicated scientific analysis, but enhanced mutual learning and dissemination.

Based on: de Wit, J., van Eekeren, N, and van der Burgt, G.J., 2006. Optimalisatie van stikstofbenutting na het scheuren van grasklaver. Bioveem-report 15.

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Rotational Experiments and Nitrogen Dynamics: Field Experiments and Modelling

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Over the years, a number of rotational experiments have been established and maintained at, or near to the Craibstone campus of SAC. The oldest of these experiments is known as the Woodlands Rotation Plots and was started in 1922. Another experiment commenced in 1961, with this being known as the Woodlands pH Plots, with an eight course rotation consisting of winter wheat, potatoes, spring barley, roots, spring oats, hay, pasture and pasture being grown on pH beds maintained at between pH4.5 to pH 7.5 in 0.5 increments.

The Woodlands Rotation Plots have maintained the same rotation of grass, grass, grass, spring oats, roots, spring barley (undersown) since its inception. Superimposed across this rotation is a range of 6 fertiliser treatments (1) no fertiliser; (2) complete fertiliser with superphosphate; (3) complete fertiliser with ground mineral phosphate; (4) nitrogen and potash only; (5) potash and phosphate only; (6) nitrogen and phosphate only. The root crop plots comprise two rows each of swedes, turnips and potatoes, and manure is applied to this phase of the rotation in all years. There are 36 unreplicated plots in all, with yield and weather data available for most years, and soil and crop analyses available for many of these. Temporal replication is possible, as every crop phase and every fertiliser treatment is present each year, with over 14 rotational cycles having been achieved to date. The data is currently being analysed with the intention of it being published in a peer reviewed journal. The long-term nature of the experiment and the data collected from it has stimulated interest from modellers, particularly those investigating issues such as climate change, and has sparked several strands of collaboration for model paramaterisation.

An additional trial, an organic one, was established in 1991 on two sites with contrasting soils and climate in the NE of Scotland, one at Craibstone (Tulloch) and one near Elgin (Woodside). It is these trials that will be the focus of the rest of the paper and are described more fully in Taylor *et al.* 2006. These rotations differed in the proportion of fertility building crops (38% ley for an 8 course rotation at Woodside; 50% ley for similar 6 course rotations at both Woodside and Tulloch; 67% ley for a 6 course rotation at Tulloch). All rotations included grazing sheep on at least part of the ley phase. There are two physical replicates of each rotation, but as with the Woodlands Rotation Plots, there is also temporal replication as each treatment is present every year. A large data set was collected on both physical (e.g. yields and quality), chemical (e.g. soil and crop nutrients) and biological (e.g. weed species and abundance; worm numbers) parameters associated with the trials. Funding for the Woodside trial ended in 2003, but the Tulloch trial is still operational and building on the existing data sets, including more recently estimates of GHG losses (including N_2O, CO_2 and CH_4). It is considered that analysis of these measurements will play a useful role in helping to inform policy and good farming practice in the future in order to reduce environmental burdens.

The results from the first 15 years of these experiments suggested that there was little difference between rotations in terms of many of the parameters being measured. For example, crop yields varied seasonally, but averaged over several years they remained constant. Likewise, there was seasonal variation in the content and concentration of key crop and soil parameters (e.g. N), but long-term, there was no significant change from the values measured at the start of the experiment. Additionally, there were only minor differences between gross margins between rotations, with the greatest differences occurring between sites where soil type and climate could account for most of the variation.

These results, which suggested an element of sustainability in the current rotations, prompted discussion on how best to move the research forward. In late December 2006, it was decided to maintain the 50% ley rotation for continuity reasons, but to include a barley treatment as well as the existing oat treatment in the first cereal after the ley. Additionally, the decision was made to modify the 67% ley rotation into a stockless system containing only 1 years ley (i.e. 16.7%) which would be cut and mulched red clover. Additional N inputs would be in the form of undersown cereals, and beans. Higher value crops such as wheat and potatoes were also included in the new rotation in line with the Organic Action Plan, but it was impossible to get agreement on which should come first after the red clover, so the plots were split with potatoes on one side and spring wheat in the other, and the following year, these were reversed. In reality, the experiment now contains four rotations, only one of which is the original. The rotations are outlined below:

50% ley (a)	G / WC	G/ WC	G / WC	SBarley	Swedes	SOats u/s WC
50% ley (b)	G / WC	G / WC	G / WC	SOats	Swedes	SOats u/s WC
16.7% ley (a)	Grass / RC	SWheat	Potatoes	SBeans u/s WC	SBarley u/s WC	SOats u/s WC
16.7% ley (b)	Grass / RC	Potatoes	SWheat u/s WC	SBeans u/s WC	SBarley u/s WC	SOats u/s GRC

G = Grass; WC = White Clover; RC = Red Clover; S = Spring; u/s = under sown

All the original plots (27m x 30m) have been split into two halves (a and b), and the routine measurements are being undertaken on all of these Half-plots in order to follow changes overtime caused by differences in the rotations. Additional samples and measurements at key crop growth stages are also being taken in order to paramaterise the SPACSYS model being developed by SAC colleagues. The data collected during the previous 16 years has also been used to paramaterise a number of other crop growth and nutrient models, including NDICEA (van der Burgt *et al.*, 2006).

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