Estimated N leaching losses for organic and conventional farming in Denmark

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Short title: *N leaching losses for organic and conventional farming*

Keywords: nitrogen, leaching, conventional, organic, agriculture

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SUMMARY

The impact of organic, compared to conventional farming practices, on N leaching loss was studied for Danish mixed dairy and arable farms using an N balance approach based on representative data. On mixed dairy farms a simple N balance method was used to estimate N surplus and N leaching loss. On arable farms the simple N balance method was unreliable (due to changes in the soil N pool). Consequently, the FASSET simulation model was used to estimate N surplus, N leaching loss and the changes in the soil N pool.

The study found a lower N leaching loss from organic than conventional mixed dairy farms, primarily due to lower N inputs. On organic arable farms the soil N pool was increasing over time but the N leaching loss was comparable to conventional arable farms. The soil N pool was primarily increased by organic farming practices and incorporation of straw. The highest increase in the soil N pool was seen on soils with a low level of organic matter. The level of N leaching loss was dependent on soil type, the use of catch crops and the level of soil organic matter, whereas incorporation of straw had a minor effect. N leaching was highest on sandy soils with a high level of soil organic matter and no catch crops. The study stresses the importance of using representative data from organic and conventional farming practices in comparative studies of N leaching loss. Lack of representative data has been a major weakness of previous comparisons on N leaching losses on organic and conventional farms.

INTRODUCTION

During recent decades there has been an increasing focus on the environmental impact of farming, including the effects on the quality of soil, air, water, biodiversity and landscape.

The loss of nitrogen to the aquatic environment and to sensitive terrestrial ecosystems, causing reduction of ground water quality and damage of terrestrial and marine ecosystems, has gained particular attention.

Agricultural systems in the EU generate a large nitrogen surplus, which is the main source of nitrogen input to water bodies (EEA 2003) and which can potentially pollute both surface and groundwaters (Nixon *et al.* 2003). The European Environment Agency (EEA 2003) concludes that nitrate in drinking water is a common problem across Europe, particularly from shallow wells and there is no evidence of any decrease in the nitrate levels in Europe's groundwater. Nitrate concentrations in rivers have remained relatively stable throughout the 1990s with the highest levels in those western European countries, including Denmark, with the most intensive agriculture (EEA 2003). In an indicator-based assessment the EEA recommend that the impact of agriculture on Europe's water resources needs to be reduced if an acceptable quality of surface and groundwater is to be achieved (Nixon *et al.* 2003).

Organic farming has gained increasing interest as an environmentally friendly production system and the EU promotes organic agriculture explicitly because of its positive effects on the environment. The principles of the International Federation of Agricultural Movements (IFOAM) state that organic farms should avoid all forms of pollution and maintain the genetic diversity of the agricultural system and its surroundings, including the protection of plant and wild life habitats (IFOAM 2004). However, these basic principles do not automatically ensure that organic agriculture reduces the environmental impact of farming. It is therefore important to evaluate whether conversion to organic agriculture actually does reduce the environmental impact of farming.

Earlier findings have shown that organic farming is usually associated with a significantly higher level of biological activity and a higher level of soil organic matter (Hansen *et al.* 2001, Stolze *et al.* 2000, Pulleman *et al.* 2003, Oehl *et al.* 2004, Mäder *et al*. 2002). Stolze *et al*. (2000) concluded that in productive areas, organic farming is currently the least detrimental farming system with respect to wildlife conservation and landscape and a higher species diversity is found in organic fields (van Elsen 2000, Pfiffner & Luka 2003).

However, there are certain discrepancies between the conclusions regarding the effect of organic farming on N leaching loss. Some argue that they can find no evidence that N leaching loss will be reduced by the introduction of organic farming practices (Kirchman & Bergström 2001, Sileika & Guzys 2003). Kirchmann and Ryan (2004) argue that organic practices might even increase nitrate leaching. Others conclude that organic farming results in lower or similar nitrate leaching rates than integrated or conventional agriculture (Stopes *et al*. 2002, Stolze *et al*. 2000, Hansen *et al*. 2000). Hass *et al*. (2002) estimated that organic farming reduced N leaching by more than 50% compared to conventional farming. Similarly, Eltun (1995) found a reduced N loss in organic compared to conventional cropping systems. Cederberg and Mattsson (2000) and de Boer (2003) found that the eutrophication potential was lower for organic than conventional milk production. However, most studies have focused on conversion to organic farming in general (Hansen *et al*. 2001, Stolze *et al*. 2000, Kirchmann & Bergström 2001, Haas *et al*. 2002, Stopes *et al*. 2002, De Neve *et al*. 2003), irrespective of possible differences between different farm types. A range of different approaches has been used to compare N leaching from organic and conventional farming systems, including field experiments, farm studies, life cycle assessments and modelling. Their conclusions have often varied significantly as the degree of N leaching is highly dependent on the choice of crops (including catch crops), farming practices, stocking rates and N inputs. This shows that generalising on the basis of a few farms or field trials is unreliable and valid comparisons between the two systems need to be representative of actual conditions and practices within the systems. This paper aims to compare N leaching losses on organic and conventional arable and mixed dairy farms at a national scale.

MATERIALS AND METHODS

This publication is based on two studies published recently in Danish. The studies focused on differences in N losses on organic and conventional mixed dairy (Kristensen *et al*. 2004) and arable farms (Berntsen *et al*. 2004), respectively. The present paper relates the two studies to one another in order to assess the effect of different production systems on N leaching losses. Mixed dairy and arable farms are chosen as examples since most organically managed land in Denmark falls into one of these two categories: accounting for 0.54 and 0.25 respectively of organically managed land in Denmark. (Berntsen *et al*. 2004). The paper builds on these two studies by discussing the interrelationships between the soil N pool and N leaching losses and the effect of production system, soil type and crop history (level of soil N). In continuation of this analysis, it discusses why previous studies have arrived at different conclusions when comparing results of N leaching losses in organic and conventional farming – and stresses the need for using representative data in order to estimate, and compare, N leaching losses from the two farming systems.

Representative data

The studies were based on data from databases representing Danish agriculture in 1999. All Danish farms are obliged to record purchases and sales for tax purposes and the yearly accounts are made with professional help. A representative set of these accounts is reported by the agricultural advisors to the Danish Research Institute of Food Economics and this data is used as the basic empirical input for the analysis of farm types presented here (see Anonymous 2004*a*, Larsen 2003). The economical data were combined with central government data on fertilizer accounts, land use (General Agricultural Register) and animal numbers (Central Husbandry Register).

The data were classified by farm types, according to the main enterprise; including cash crop arable farms and mixed dairy farms (defined here as farms with 0.90 of the livestock being dairy cattle) and separated into organic and conventional farms. The data classification and separation methods are outlined in Kristensen and Kristensen (2004).

The N balance methodology

The representative data were analysed by using an N balance approach (Watson et al. 2002). Farm-scale N balances or budgets are the outcome of a simple N accounting process, which details all the inputs to, and outputs from, a farm over a fixed period of time. The underlying assumption of an N budget, or balance, is that of mass balance: i.e. N inputs to the system minus N outputs from the systems (including N leaching loss) equal the change in storage within the system (Meisinger & Randall 1991). The N balances or budgets can differ depending on the system boundaries and the account details, i.e. which inputs and outputs are included and whether internal flows are taken into account (Watson et al. 2002). There is no universally correct approach to compiling nutrient budgets, rather the methodology chosen should be appropriate to the specific case (Oenema & Heinen 1999). Figure 1 illustrates the main N flows, and the boundaries for the N balance, used in the present paper. *Farm N balances* are estimated as the inputs subtracted by the outputs. *Field N balances* at farms with livestock are calculated by subtracting N losses from stables and storage from the farm N balance. On arable farms, the field N balance is the same as the farm N balance. The field N balance is the sum of atmospheric N losses, changes in the soil N storage and N leaching losses. Hence changes in the soil N storage are one of the factors that influence N leaching loss.

Choice of methods

Two different methods, based on N balance methodology, were used to estimate the effect of organic farming on N leaching loss on representative mixed dairy and arable farms, respectively. The reason for this lies in the attributes of the different systems as explained in the following. Besides the absence of mineral fertilizer, the conversion from conventional to organic mixed dairy farming typically implies a slightly increased proportion of grass/clover in the crop rotation, a reduced stocking rate, a reduced input of supplementary feed and a reduced milk yield per cow (Table 1). It can be presumed that changes in the soil N pool will be similar on organic and conventional mixed dairy farms, due to a high internal N turnover in both systems and the similarities in farming practice and crop rotations (Table 1). It can be assumed that the soil N contribution resulting from a higher proportion of grass/clover on organic mixed dairy farms approximately counterbalances the greater amount of manure and plant residues on conventional farms due to a higher stocking rate and higher crop yields (Table 1). If we assume soil N changes to be similar on the two types of mixed dairy farms, simple N balances can be used estimate the difference in N leaching loss on those farms.

By contrast to mixed dairy farms, there are considerable differences in the farming practices and crop rotations employed on organic and conventional arable farms (Table 1). The conversion from conventional to organic arable farming implies a shift from mineral to organic fertilizer, in which high levels of inputs of mineral fertilizer are replaced by imports of manure and the introduction of grass/clover in crop rotations (Tables 1 and 7). Furthermore, organic arable farms maintain a higher proportion of permanent grassland (Table 1), incorporate more straw into the soil (as observed on pilot farms) and are make more efficient use of catch crops than conventional arable farms. Net mineralization from the soil, straw incorporation and catch crops has a considerable influence on the distribution of N between yield, soil N and leaching (Di & Cameron 2002, Olesen *et al*. 2004). This suggests that the changes in the soil N pool on conventional and organic arable farms cannot be assumed to be similar. To account for changes in the soil N pool on arable farms, as affected by farming practices and crop rotations, the whole-farm, dynamic simulation FASSET model (Berntsen *et al*. 2003) was used. N balances were calculated, including the possible changes in the soil N pool, from the datasets representing Danish agriculture in 1999 (described above).

Simple N balances

The simple N balances on the mixed dairy farms were based on representative data from 1999 (Table 1). The statistics were divided into eight farm categories, depending on farm type, conventional/organic and soil type (Table 1). The data for mixed dairy farms represents a fraction of 0.85 of the Danish dairy herd (Anonymous *2004b*).

The N-surplus on the farm level (farm N balance) was estimated for each farm category by subtracting N outputs from N inputs. Field N balance was estimated by subtracting N loss at the stables and during storage from the farm N balance. The sum of N leaching loss and possible soil N changes was estimated by subtracting aerial N loss from denitrification and ammonia volatilisation from the field N balance.

The calculations were based on information from the representative dataset concerning area, stocking rate, milk and meat production, yield of cash crops etc. The amounts and nutrient value of imported feeds, imported fertilizer and home-grown feed were not available in the representative dataset and were estimated.

In order to calculate the field N-balance (Sveinsson *et al.* 1998) two main assumptions were made. Firstly, roughage yields were assumed to be equal to measured yields on 100 private pilot farms in the period 1989-2002 (Kristensen *et al.* 2003). Secondly, imports of concentrates and grains were calculated from yields of home-grown feed and animal products. The N-efficiency of conventional dairy herd was assumed to be 0.24 (Poulsen & Kristensen 1998) and 0.23 for organic farms, (the latter figure derived from measurements on 30 organic dairy pilot farms). The difference between the herds' requirements and home-produced feed was assumed to have been imported.

N_2 fixation in grass/clover fields was estimated at 150 kg N per ha on organic farms and 103 kg N per ha on conventional mixed dairy farms. This follows the findings of earlier survey work on 100 private, pilot, farms (Kristensen *et al.* 1995). In sole crop legumes fixation was calculated from yield (Høgh-Jensen *et al.* 2003). The total import of mineral N-fertilizer was calculated per crop. In Denmark each crop has an N-quota that consists firstly of 0.58 of total N in home-produced animal manure (considered as the fraction of plant available N): the rest can be made up by mineral N-fertilizer. Thus the import of mineral N-fertilizer can thus be calculated, when the total manure production and the exchange of manure are known. Ammonia losses were estimated in accordance with Poulsen and Kristensen (1998) and Illerup *et al.* (2003), and denitrification was estimated in accordance with Vinther and Hansen (2004). The losses were calculated by assuming average emissions depending on animal breed, stall and manure system and good management for utilization (see calculated emissions in Kristensen *et al.* 2003).

FASSET model simulations

FASSET is a validated whole-farm, dynamic simulation model (Berntsen *et al.* 2003). This study utilises the field module of this programme, which consists of crop and soil sub-modules to estimate N leaching and soil N changes on arable farms.

The crop module calculates dry matter (DM) production from the light interception and a radiation use efficiency that depends on temperature, crop nitrogen status and water availability. Light interception is calculated from leaf area, which in turn is simulated using expansion rates depending on crop phenological stage, temperature, N uptake, above-ground DM and drought stress. Thermal age and day length govern the phenological development.

The soil module divides the soil profile into a number of homogenous layers, each of 5 cm depth. The hydrological processes considered include the accumulation and melting of snow, interception of precipitation by the crop canopy, evaporation from the canopy and soil surfaces, infiltration, water uptake by plant roots, transpiration and vertical movement of water in the soil profile. Soil temperature is calculated according to the principles in Jansson (1996), and ice formation is described. The crop-soil interaction is described in further detail in Olesen *et al.* (2002).

In order to conduct the FASSET simulations land use in the representative Danish dataset (Table 1) was generalised into a 10-field crop rotation (Tables 2 and 3). The organic crop rotation has a high proportion of spring cereals and a fraction of 0.2 grass/clover, while cereals, primarily winter cereals, dominate the conventional crop rotation. Together with management details these crop rotations were used as inputs for the FASSET model.

The effects of different management practices on N leaching loss were evaluated by constructing several scenarios for organic and conventional arable farming, including catch crops (+/-) and incorporation of straw (+/-). Furthermore, the fertilization level (1.0, 0.5 or 0.0 of that in the baseline scenario) and the proportion of grass/clover in the crop rotation were varied in the organic scenarios. The following organic and conventional scenarios were used in the modelling of arable farms:

Conventional arable farming

- **Basic:** Crop rotation with 0.06 catch crops and N import as provided by the statistics.
- **+ catch crops:** Basic crop rotation but with added ryegrass in three more fields.
- **+ incorporation of straw:** Basic crop rotation with the incorporation of straw in all fields.

Organic arable farming

- **Basic:** Crop rotation including a fraction of 0.2 grass/clover, of which half is used for silage and half for green manure
- **+ catch crops:** Basic crop rotation but with added catch crops (a mixture of white clover and ryegrass) in three more fields.
- **+ incorporation of straw:** Basic crop rotation with straw incorporation in five fields.
- **+ straw and catch crop:** Combination of the two above-mentioned scenarios.
- **0.5 fertilizer:** Basic crop rotation but using only 0.5 of the organic fertilizer in the baseline scenario.
- **0 fertilizer:** Basic crop rotation without any added organic fertilizer.

- **0.10 grass/clover:** The fraction of grass/clover cover is reduced from 0.2 to 0.1. This is used for green manure with that used for silage (see Table 2) being replaced by spring barley followed by a catch crop. The added fertilizer to the crop rotation is adjusted to allow spring barley to receive fertilizer too. The total amount of added fertilizer remains unchanged.

N balances on the farm and field level, including N leaching loss and changes in the soil N pool, were calculated for three soil types (sandy soil, loamy sand or sandy loam) and two soil fertility levels (high or low level of soil organic matter) (Table 4), these representing the variation in Danish soil types (Heidmann *et al.* 2002). Each simulation used climatic data from Foulum (56°30’N, 9°35’E), Denmark, for the 10-years crop rotation. To reduce noise from climatic variations, the model was restarted 15 times with different starting years. On top of this, the model was started at each of the 10 different positions in the crop rotation.

RESULTS

Simple N balances

The organic mixed dairy farms had a lower stocking rate than the conventional farms (Table 1) and milk production per cow was 7% lower on the organic farms than the conventional farms (Table 1).

The main difference in N input between conventional and organic mixed dairy farms was the import of mineral fertilizer (Table 5). However, the higher N input through N_2 fixation on organic mixed dairy farms counterbalanced the higher N input from import of supplement feed on conventional mixed dairy farms (Table 5). The simple farm N balances showed that, at the farm level, the N surplus was 35% lower on organic mixed dairy farms than on conventional farms (Table 5). Organic mixed dairy farms had a higher field N efficiency than conventional mixed dairy farms (Table 5).

The individual effects of changes in the four main assumptions on the simple farm N balances are shown in Table 6. The greatest change could be seen when the N_2 fixation was assumed to be 25 % higher. Here, the farm N balance would increase by 13 kg N per ha per year more on organic farms than on conventional ones, this would increase the farm N balance on organic farms, to just 27% less than on conventional ones (Table 6). The change in the other assumptions (N-efficiency of dairy herd, N in fodder and crop yields) only changed the difference in farm N balance between organic and conventional farms by between 0-8 kg N per ha per year (Table 6).

The N losses due to N leaching loss and soil N changes were on average 40% lower on organic than conventional mixed dairy farms (Table 5). They were generally higher on sandy soils than on sandy loam soils (Table 5). Higher stocking rate on conventional farms increased the N losses due to leaching loss and soil N change (Table 5). However, conventional farms with a lower stocking rate than organic farms still had a higher N loss on both types of soil.

FASSET model simulations

N balances, including N leaching loss and soil N changes, were affected by farm type, farming practices (Table 7), soil type and fertility level (Table 8).

There was no difference in the estimated N leaching loss between organic and conventional arable farming in the baseline scenarios (averaged over soil types and fertility levels see Table 7). Organic arable farms had a higher field level N surplus than conventional farms in the baseline scenarios, as they imported an almost equal amount of

N, via N_2 fixation and manure, but had lower N yields than the conventional farms (Table 7). Averaged over different soil types and fertility levels, the baseline scenarios showed an increase in the soil N pool on the organic arable farms, while the soil N pool on the conventional farms decreased. (Table 7).

N leaching loss was primarily affected by soil type. In the baseline scenarios it was 26-33 kg N per ha per year higher on the sandy soil than on the sandy loam soil (Table 8). However, sandy loam soils had a higher rate of N loss to denitrification than sandy soils (Table 8). The soil fertility level also affected N leaching loss. It was 8-15 kg N per ha per year higher on soils with a high soil fertility level, with the greatest difference on sandy soils, and the least difference on sandy loam soils (Table 8). The estimated N leaching loss was approximately 40 kg N per ha per year higher on sandy soils with a high level of soil organic matter than on loamy sand soils with a low level of soil organic matter (Table 8). Soils with a low fertility level had a higher field N balance, due to higher N_2 fixation and lower yields, but a much higher incorporation of soil N.

The increased use of catch crops was the single most efficient farming practice for reducing N leaching loss: by approximately 9 kg N per ha per year on organic farms and 7 kg N per ha per year on conventional ones (Table 9). However, one should note that only a 0.30 of the fields in the crop rotation would have extra catch crops. The estimated reduced N leaching loss was primarily due to an increase in the soil N pool in the catch crop scenarios compared to the baseline scenarios (Table 7). A reduction in the import of manure in the organic scenarios only reduced the N leaching loss by 2-4 kg N per ha year. Incorporation of straw had a minor effect on N leaching loss (Table 9), but increased the soil N pool (Table 10). Averaged over soil types and soil fertility levels, the soil N pool increased in the baseline organic scenario whereas it decreased in the baseline conventional scenario (Table 7). Changes in the soil N pool were primarily dependent on the existing soil fertility level and incorporation of straw. On soils with a low fertility level, the contribution to the soil N pool was approximately 26 kg N per ha per year higher than on soils with a high fertility level (Table 10). A decrease in the soil N pool was only seen in soils with a high level of organic matter (Table 10). Incorporation of straw increased the soil N pool by approximately 14 and 26 kg N per ha per year, on organic and conventional farms, respectively. In these scenarios the incorporation of straw was increased by a factor of 0.6 for organic farms, and by 1.0 for conventional farms (Tables 2 and 3). A reduction in the import of manure on organic farms decreased the soil N pool by approximately 9 kg N per ha in the 0.5 reduction scenario and by 19 kg N per ha per year in 0 fertilization scenario. The soil N pool decreased by approximately the same amount in the organic cropping system without fertilization as it did in the basic conventional cropping system (Table 10). The introduction of more catch crops increased the soil N pool by on average 8 kg N per ha per year compared to the baseline scenarios (Table 10). Decreases in the soil N pool were most notable in the baseline conventional systems (with and without catch crops) and in the organic scenario without fertilization on soils with a high fertility level (Table 10). The highest increase in the soil N pool occurred in the organic scenario with incorporation of straw and catch crops in three more fields on soils with a low fertility level (Table 10).

DISCUSSION

Methods for estimating N leaching loss

It is not feasible to directly compare the absolute level of N leaching loss from arable and mixed dairy farms as two different approaches were used to evaluate differences between organic and conventional farms. However, the difference between organic and conventional farms within each farm type and method can be evaluated.

In the few studies that have been conducted on the effect of organic farming on N leaching loss, several different methods have been used (e.g. Stopes *et al*. 2002, Haas *et al*. 2002, Dalgaard *et al*. 2002). One problem in comparing the performance of farming systems with respect to N leaching loss is that it is very difficult to measure directly. Therefore, such comparisons are often made on the basis of N balances, rather than from actual measures (Dalgaard *et al*. 2002, Dalgaard *et al*. 1998, Hansen *et al*. 2000). Often a systems approach is used, as a separate focus on crop fertilisation or feeding practices does not adequately capture the complex interactions between animal and crop production and the uncertainties of herd N production and of crop N utilisation, all of which influence N losses from mixed dairy farms (Halberg *et al.* 1995). Finally, the generalisation of results from field trials and a few farm studies may be questioned, as differences in N leaching on organic and conventional farms are often due to differences in crop rotations or N inputs (Hansen *et al.* 2000). The choice of crops, including catch crops, and the level of N input all have considerable influence on the estimated N leaching loss. It is more reliable to estimate N leaching loss on the basis of data that most closely resembles the actual practices of organic and conventional farming. The use of unrepresentative data has been a major weakness in previous studies comparing N leaching loss in conventional and organic farming, and the present study seeks to address this shortcoming. Comparisons of organic and conventional farming systems have been criticized by Kirchmann and Bergström (2001), who argue that unequal conditions such as differences in N input and crop rotations (including the proportion of catch crops) between organic and conventional farming systems need to be kept the same in order to obtain conclusive results. However, it seems meaningless to do so, and very hard to justify, as they are characteristic differences between the two systems.

Kirchmann and Bergström (2001) also argue that comparisons of N leaching loss in organic and conventional farming systems should be measured per yield unit and not per ha farmland. They argue that N leaching loss per yield unit is a more appropriate measure on the assumption that a certain amount of food has to be produced within a country, whether conventionally or organically. This could open the choice of producing food more intensively in a certain areas, involving higher N leaching loss per ha, but of gaining more area for “wild nature”. However, farmers produce on the land that they have and assess their income per ha and not according to a certain production quota. Moreover, from an environmental point of view it is preferable to measure N leaching loss per ha farmland, based on the assumption that any area of farmland will either be cultivated organically or conventionally. Furthermore, the European cultural landscape and the species diversity of grasslands are often better maintained and enhanced through keeping land in cultivation e.g. grazing of meadows rather than letting it return to “wild nature” (Van Wieren 1995, Pykälä 2005; 2003).

The assumption made for mixed dairy farms, that changes in the soil N pool are likely to be similar on organic and conventional farms, is a prerequisite for using the simple N balance method for estimating N leaching loss. However, if this assumption did not hold, the organic mixed dairy farms would probably make a slightly higher contribution to the soil N pool, as is the case for arable farms (Table 8) due to more catch crops and a higher proportion of grass/clover. Consequently, the estimated N leaching loss on organic mixed dairy farms would be lower than our figures suggest and, the difference in N leaching loss between organic and conventional mixed dairy farms would be greater. The FASSET model has proven able to simulate environmental effects of farming (Berntsen *et al*. 2003) and have thus (based on the same national data) taken the dynamic processes concerning the soil N pool into account. The current FASSET version does not include a cattle feeding and management model and can thus not be applied to dairy farms. However, the simple N balance model seems more appropriate for mixed dairy farms as the soil N pools can be assumed to be comparable and the N dynamics between fields and stables are much more complex.

N leaching loss on organic versus conventional farms

N leaching loss is affected by various soil, climatic and management factors. Management factors, such as a reduction of nitrogen inputs and the use of catch crops can be important tools in reducing such losses (Di & Cameron 2002, Kirchmann *et al.* 2002).

The main factor influencing the higher N surplus on conventional mixed dairy farms was the higher level of N inputs (due to imports of mineral fertiliser and a higher import of fodder) which were not matched by correspondingly higher N outputs. This finding is in accordance with earlier studies (De Boer 2003, Dalgaard *et al.* 2002, Hansen *et al.* 2000). Other studies have also found a higher N-efficiency on organic mixed dairy farms compared to conventional ones (Dalgaard *et al.* 1998, Halberg *et al.* 1995). The effect of changes in five of the important assumptions (Table 6) was not dramatic and the farm N surpluses thus had a relatively low degree of sensitivity to changes in assumptions. Many studies, based on systems approaches, have estimated lower N losses on organic mixed dairy farms than on conventional ones (see De Boer 2003, Dalgaard *et al.* 2002, Cederberg & Mattsson 2000, Dalgaard *et al.* 1998, and Halberg *et al.* 1995). However, the lower stocking rate on organic mixed dairy farms was not the main causative factor for lower N leaching loss on organic farms. On conventional farms the N surplus is closely related to the stocking rate (LSU/ha) (Halberg *et al.* 1995). However, the present results show that conventional farms with a lower stocking rate (category: <1.4 LSU/ha) than organic farms (Table 1) still have a considerable higher estimated N leaching loss (Table 5); this is in line with findings by Dalgaard *et al.* (1998) and Halberg *et al.* (1995). Eriksen *et al.* (1999) showed that nitrate leaching losses in an organic mixed dairy crop rotation had only a weak relation to stocking density. Throughout the 1990s the N surplus of conventional mixed dairy farms has been diminishing in Denmark whereas the on organic mixed dairy farms it has been more stable (Kristensen *et al.* 2003; 2004). However, several studies have shown a lower N surplus and N leaching loss on organic than on conventional mixed dairy farms, primarily due to lower N inputs (De Boer 2003, Dalgaard *et al.* 2002, Cederberg & Mattsson 2000, Dalgaard *et al.* 1998 and Halberg *et al.* 1995).

Modelling the basic conventional and organic scenarios on arable farms, resulted in very similar estimates of N leaching loss for the two systems (Table 9). Only a few studies comparing N leaching loss on organic and conventional arable farms have been made. Most of these have focused on organic farming in general, using field studies and arriving at different results. Eltun (1995), Haas *et al.* (2002) and Poudel *et al.* (2002) found a lower N leaching loss in organic farming systems compared to conventional, whereas Sileika & Guzys (2003) found no difference between the two farming systems. These different results may depend on the methods, basic assumptions made and conditions in the studied farming systems. The present model simulations of arable farms show that N leaching loss can be affected by: crop rotation, including catch crops (see below); management practices; soil type and total input of fertilizer. Different assumptions and conditions can give results that reflect favourably on either system. This again shows the importance of using representative data on farming practice at the regional or national scale.

The results of the N loss simulations from the FASSET model corresponded with previous studies showing the relative effect of different measures such as soil type, catch crops, soil fertility level etc. Olesen *et al.* (2004) carried out an organic arable crop rotation trial in Denmark on three different locations; coarse sandy soil, loamy sand soil and sandy loam soil. They found a higher N leaching loss on the coarse sandy soil than on the other two soil types, in accordance with the present results. They also found that the use of catch crops reduced N leaching loss by 23% to 38%, again in agreement with the present results. Similar effects from using catch crops were also found by Eriksen *et al.* (2004) (in an organic mixed dairy crop rotation), Hansen and Djurhuus (1997) and Aronsson & Torstensson (1998). However, it might not be possible to fully exploit the potential of catch crops for reducing N leaching loss in organic farming, as weed harrowing in a bare fallow might sometimes be needed to manage weeds. In accordance with Di & Cameron (2002), straw incorporation was found to have little effect on N leaching loss. N leaching losses were higher on soils with a high level of soil organic matter ("high soil fertility"- corresponding to approximately 14000 kg total N/ha) than on soils with a low fertility (circa. 9000 kg total N/ha) (Tables 4 and 9).

The increases in the soil N pool for the organic and the decreases for the conventional baseline scenarios are presumed to be due to management practices such as the exclusive use of manure, catch crops, grass-clover etc. Christensen and Johnston (1997) showed that long-term applications of large amounts of farmyard manure increases soil organic matter and the soil N pool. Pulleman *et al.* (2003), Shepherd *et al.* (2002) and Mäder *et al.* (2002) all found a greater soil organic matter content on organic farms than on conventional farms. However, Gosling & Shepherd (2005) found no significant difference in total soil organic matter on organic and conventional farms, except for a higher level on organic fields receiving farmyard manure compared to conventional fields having the straw removed and receiving no farmyard manure. A higher carbon content of soils increases the total amount of stored soil N until the upper limit of the amount of C and N that a soil can store, (depending on soil texture, climate and management) is reached, and from then on there is a risk of N leaching (Schipper *et al.* 2004). However, the present results show that the changes in the soil N pool were minor compared to the difference in total amount of N within high and low soil fertility soils (approx. 5000 kg N per ha). The more fertile soils showed the greatest decline in the soil N pool in accordance with Kätterer *et al.* (2004), while soils with low fertility had the greatest increase in the soil N pool, in accordance with Christensen & Johnston (1997). Straw incorporation was the most effective management practice in the tested scenarios to increase the soil N pool. In a long-term trial, Christensen and Johnston (1997) found that incorporation of straw increased the soil N pool, but to a lesser degree than using farmyard manure. The level of fertilization and the use of catch crops also had an effect on the change in the soil N pool.

CONCLUSION

Several factors influence N leaching loss, and this emphasises the importance of using representative data when comparing organic and conventional farming practices. Organic mixed dairy farms lose less N through leaching than conventional mixed dairy farms, primarily due to differences in N inputs. Organic arable farms are increasing their soil N pool, but their N leaching losses are comparable to those of conventional arable farms. Catch crops can be important tools in reducing N leaching loss, especially on sandy soils where N leaching loss can be higher than on sandy loam soils.

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Figures

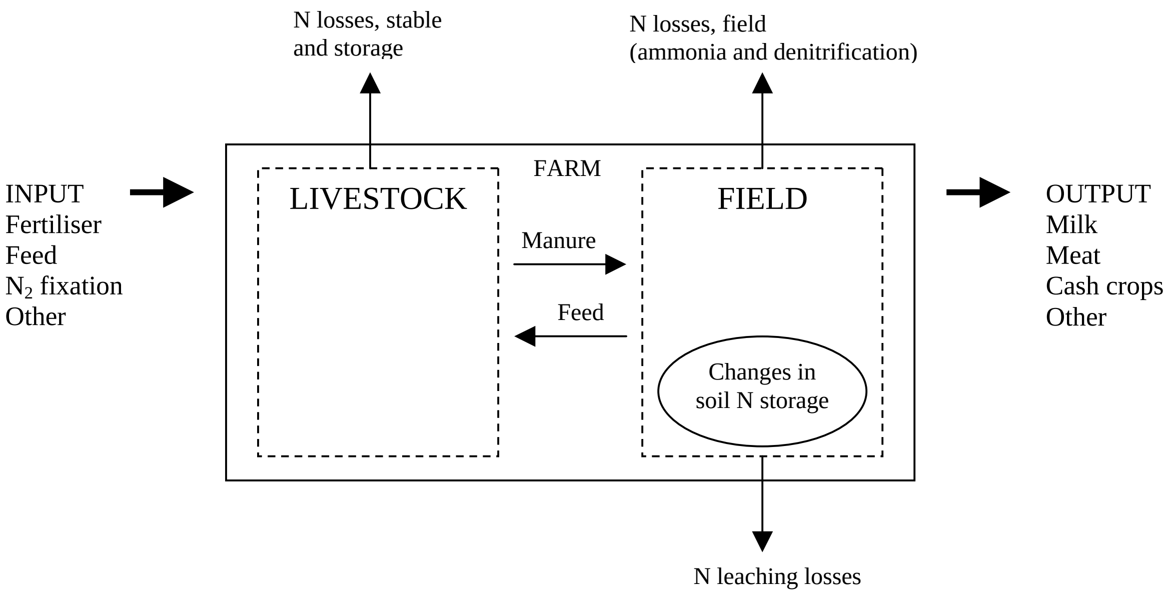

Figure 1. The main N flows used in the N balance. Farm N balances are the inputs subtracted by the outputs. Field N balances at farms with livestock are found by subtracting N losses from stables and storage from the farm N balance. At arable farms, the field N balance equals to the farm N balance. The field N balance are the sum of atmospheric N losses, changes in the soil N storage and the N leaching losses.

Tables

Table 1. Representative characteristics and area based averages of mixed dairy and arable farms in 1999, Denmark.

	Mixed dairy farms								Arable farms	
	Organic			Conventional					Organic	Conven-tional
	Sandy	Sandy loam	Ave-rage	Sandy		Sandy loam		Ave-rage	Average	Average
LSU*/ha:				<1.4	1.4-2.3	<1.4	1.4-2.3			
Representativity										
Number of farms in dataset	125	24	149	83	182	23	32	350	137	105
Represented agricultural area (1000 ha)	71	10	81	156	261	43	43	530	51	294
Herd										
Cows per farm (cows/farm)	85	62	82	48	67	55	55	61	0	0
LSU* per farm (LSU/farm)	133	100	128	81	109	87	84	99	13	2
Stocking rate (LSU/ha)	1.3	1.1	1.3	1.0	1.7	0.9	1.7	1.5	0.3	0.0
Area										
Farm area (ha/farm)	102	88	100	81	65	99	50	68	37	72
Crop rotation (fraction of farm area):										
Permanent grass	0.09	0.11	0.09	0.09	0.11	0.09	0.08	0.09	0.08	0.01
Set-aside	0.05	0.05	0.05	0.07	0.06	0.06	0.04	0.06	0.07	0.09
Cereal for harvest	0.14	0.23	0.15	0.40	0.19	0.46	0.32	0.29	0.51	0.68
Maize/whole crop silage	0.29	0.23	0.29	0.16	0.33	0.13	0.21	0.27	0.09	0.00
Grass/clover in rotation	0.41	0.33	0.40	0.18	0.26	0.14	0.25	0.22	0.12	0.01
Other crops	0.02	0.05	0.02	0.10	0.05	0.12	0.10	0.07	0.13	0.21
Production										
Cereal yield (t/ha)	4.1	4.4	4.2	5.2	4.9	5.6	5.4	5.2	3.4	5.9
Milk yield (kg milk/cow/year)	6861	6811	6855	7431	7429	7227	7288	7373	0	0

* Livestock units (LSU), DK definition: 0.85 LSU = 1 dairy cow on 7500 l milk/year.

Table 2. Organic arable crop rotation 1999 for the FASSET simulation model. Furthermore possible catch crops and incorporation of straw are noted.

Organic crop rotation	Conventional pig slurry kg N/ha	Organic manure kg N7ha	Incorporation of straw	Catch crops	Type of catch crop
1. Spring barley		83	+/-	+/-	Ryegrass
2. Field pea			+	-	
3. Rye	85		+/-	+/-	Ryegrass
4. Spring wheat + catch crop		83	+/-	+	Grass/ clover
5. Spring barley	85		+/-	+/-	Grass/ clover
6. Spring barley + catch crop		83	-	+	
7. Grass/clover, silage				-	
8. Grass/clover, set-aside				-	
9. Spring wheat + catch crop	56		+/-	+	Ryegrass
10. Spring barley/field pea, silage + catch crop	43		-	+	Grass/ clover
Average	27	25			

Table 3. Conventional arable crop rotation 1999 for the FASSET simulation model. Furthermore possible catch crops and incorporation of straw are noted.

Conventional crop rotation	Conventional pig slurry kg N/ha	Mineral fertilizer kg N/ha	Incorporation of straw	Catch crops	Type of catch crop
1. Spring barley	115	38	+/-	-	
2. Winter barley		151	+/-	-	
3. Winter oilseed rape	80	109	+	-	
4. Winter wheat		134	+/-	-	
5. Winter wheat		169	+/-	+/-	Ryegrass
6. Spring barley +catch crop	115	38	+/-	+	Ryegrass
7. Spring barley	115	38	+/-	+/-	Ryegrass
8. Spring barley		124	+/-	-	
9. Winter wheat		134	+/-	-	
10. Rye		111	+/-	+/-	Ryegrass
Average	39	95			

Table 4. Carbon content in soil at high and low fertility level used at the arable farms for the FASSET simulation model.

Depth (cm)	Low t C/ha	High t C/ha
0-25	48	79
25-50	29	48
50-75	8	8
75-100	5	5
Total	90	140

Table 5. Simple N balances at representative mixed dairy farms in Denmark, 1999 (kg N/ha/year).

	Organic			Conventional				
	Sandy	Sandy loam	Average	Sandy		Sandy loam		Average
LSU/ha:				<1.4	1.4-2.3	<1.4	1.4-2.3	
Stocking rate (LSU/ha)	1.3	1.1	1.3	1.0	1.7	0.9	1.7	1.5
Input								
Mineral fertilizer	0	0	0	104	95	103	83	95
Organic fertilizer and livestock*	9	1	8	8	1	6	1	1
Supplement feed	49	41	48	45	103	41	108	90
Straw for bedding*	7	6	7	1	9	0	8	6
Fixation	78	68	76	23	34	21	35	29
Precipitation	16	16	16	16	16	16	16	16
Total input	158	131	155	197	259	188	251	238
Output								
Milk	-28	-24	-28	-23	-40	-21	-41	-35
Meat	-6	-6	-6	-8	-10	-8	-10	-10
Cash crops	-2	-7	-2	-18	-4	-26	-8	-11
Total output	-36	-36	-36	-49	-55	-55	-59	-55
Farm N balance	122	95	119	148	204	133	192	183
N loss, stable and storage	-18	-16	-18	-15	-24	-13	-27	-22
Field N balance	104	79	101	133	180	120	165	160
Field N efficiency†	0.55	0.60	0.55	0.48	0.44	0.50	0.46	0.45
N loss, field								
Fertilization, spreading	-11	-9	-11	-12	-17	-11	-16	-15
Crops	-2	-2	-2	-4	-4	-4	-4	-4
Denitrification	-12	-32	-14	-12	-15	-34	-34	-17
Leaching and soil N changes‡	-79	-36	-74	-105	-144	-71	-111	-124

* Net import = import – export of manure, straw and living animals
† Field N efficiency = output / input
‡ Leaching = field N balance – aerial N loss (fertilization+crops+denitrification) +/- soil N change.

Table 6. Changes in simple N balances on mixed dairy farms in 1999 as affected by changes in certain assumptions (kg N/ha/year).

	Organic			Conventional				
	Sandy	Sandy loam	Average	Sandy		Sandy loam		Average
LSU/ha:				<1.4	1.4-2.3	<1.4	1.4-2.3	
Farm N balance								
Changes in assumptions:								
- 25% higher N_2 fixation	20	18	20	6	9	5	9	7
- 10% lower N-efficiency of dairy herd	10	8	10	7	13	7	14	11
- 10% higher N in homegrown fodder	-9	-8	-9	-10	-10	-10	-10	-10
- 10% higher crop yields	-12	-10	-11	-4	-2	-5	-3	-3

Table 7. N balances for all arable farm scenarios as an average over soil types and soil fertility levels using the FASSET simulation model (kg N/ha/year).

	Organic							Conventional		
	Basic	+catch crop	+straw	+straw, catch crop	0.5 fertilizer	0 fertilizer	0.10 grass/ clover	Basic	+catch crop	+straw
Input										
Mineral	0	0	0	0	0	0	0	95	95	95
Organic	52	52	52	52	26	0	52	39	39	39
Fixation	79	83	79	84	82	87	62	0	0	0
Other*	16	16	16	16	16	16	17	16	16	16
Total input	147	151	147	152	125	103	130	150	150	150
Output										
Grains	-44	-47	-44	-46	-40	-35	-46	-83	-85	-83
Straw + silage	-42	-44	-30	-31	-39	-37	-33	-26	-27	0
Total output	-86	-91	-74	-77	-79	-72	-79	-110	-112	-83
Field N balance	61	60	73	75	46	31	52	40	38	67
N loss										
Leaching	-36	-27	-33	-26	-34	-32	-33	-36	-29	-35
Ammonia	-3	-3	-3	-3	-2	0	-3	-2	-2	-2
$N_2 + N_2O$	-11	-11	-11	-11	-9	-8	-9	-10	-10	-12
Total N loss	-49	-41	-47	-41	-44	-40	-46	-48	-42	-48
Storage										
Soil	13	22	27	37	4	-6	9	-6	1	20
Mineral N	-2	-3	-2	-3	-3	-3	-3	-2	-5	-2

* N deposition and seed N

5

Table 8. N balances for the basis arable farm scenarios at different soil types using the FASSET simulation model (kg N/ha/year).

	Organic						Conventional					
	Sandy		Loamy sand		Sandy loam		Sandy		Loamy sand		Sandy loam	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Input												
Mineral	0	0	0	0	0	0	95	95	95	95	95	95
Organic	52	52	52	52	52	52	39	39	39	39	39	39
Fixation	75	81	74	81	78	84	0	0	0	0	0	0
Other*	16	16	16	16	16	16	16	16	16	16	16	16
Total input	143	149	143	149	146	153	150	150	150	150	150	150
Output												
Grains	-44	-40	-46	-41	-49	-44	-84	-77	-85	-78	-93	-83
Straw + silage	-42	-38	-44	-40	-46	-42	-28	-24	-30	-25	-27	-22
Total output	-87	-78	-91	-81	-96	-86	-112	-101	-115	-103	-120	-106
Field N balance	56	71	52	68	50	67	38	49	34	46	29	44
N loss												
Leaching	-56	-42	-44	-33	-24	-16	-56	-41	-46	-32	-23	-15
Ammonia	-3	-3	-3	-3	-3	-3	-2	-2	-2	-2	-2	-2
$N_2 + N_2O$	-3	-3	-8	-7	-24	-19	-3	-3	-7	-6	-23	-18
Total N loss	-62	-48	-55	-42	-51	-38	-62	-45	-56	-41	-48	-35
Storage												
Soil	-4	24	0	26	3	30	-21	4	-18	7	-16	9
Mineral N	-2	-1	-3	-1	-3	-1	-3	-1	-3	-1	-4	-1

* N deposition and seed N

Table 9. N leaching loss (kg N/ha/year) for all arable farm scenarios at the different soil types and soil fertility levels using the FASSET simulation model.

	Sandy		Loamy sand		Sandy loam		Average
	High	Low	High	Low	High	Low	
Organic							
Basic	56	42	44	33	24	16	36
+ catch crop	46	33	35	24	16	10	27
+ incorporation of straw	53	39	42	30	22	15	33
+ straw and catch crop	44	31	34	23	15	9	26
0.5 fertilization	52	39	41	30	23	16	34
0 fertilization	49	37	39	29	22	15	32
0.10 grass/clover	52	38	41	30	23	15	33
Conventional							
Basic	56	41	46	32	23	15	36
+ catch crop	49	33	40	26	18	10	29
+ incorporation of straw	56	40	46	32	21	14	35

Table 10. Change in soil N pool (kg N/ha/year) for all arable farm scenarios at the different soil types and soil fertility levels using the FASSET simulation model. Average over 10 years.

	Sandy		Loamy sand		Sandy loam		Average
	High	Low	High	Low	High	Low	
Organic							
Basic	-4	24	0	26	3	30	13
+ catch crop	6	34	8	35	12	39	22
+ incorporation of straw	11	37	15	40	18	44	27
+ straw and catch crop	21	47	24	50	28	54	37
0.5 fertilization	-13	15	-10	17	-6	20	4
0 fertilization	-23	4	-19	7	-16	10	-6
0.10 grass/clover	-8	20	-5	22	-2	25	9
Conventional							
Basic	-21	4	-18	7	-16	9	-6
+ catch crop	-14	12	-12	13	-9	16	1
+ incorporation of straw	5	29	9	32	12	34	20