DENMARK

Part II: N turnover on Danish mixed dairy farms

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Summary

Nitrogen balances from three sets of pilot farms from 1989 to 2003 are presented, and a set of representative farms based on Danish farm accounts from 1999. The data represent typical management and the range between farms is well documented. The results from all independent analyses show the same tendencies. The conventional dairy farms have reduced their farm gate N surplus with around 30% during the 1990s. Since 1994 the surplus has been 173-177 kg N ha^{-1} with a stocking rate of about 1.5-1.7 LSU ha^{-1} (1 LSU = 0.85 Holstein dairy cow). In the same period N surplus on organic dairy farms was between 112-128 kg N ha^{-1} with a stocking rate of 1.1-1.3 LSU ha^{-1}. On the conventional farms the N-surplus significantly increased with stocking rate, with the ratio of 78 kg N LSU^{-1}. The difference between farm N-balance of conventional and organic dairy production systems was 57-61 kg N ha^{-1} corrected for stocking rate. An average field level balance was estimated using simple models of ammonia losses and denitrification to subtract gaseous emission from the farm gate balance. It is discussed how assumptions regarding soil-N changes can give estimates of N leaching.

Background

Dairy production is characterised by major internal flows between field and herd, both with fodder and recycling of animal manure. Grass/clover swards for grazing are is important on many farms. This paper gives a description of the internal and external N flow and N loss on Danish dairy farms from 1990 to 2003. After entering into the EU in 1972, a specialization from mixed dairy and pig farms has been going on towards bigger and more specialized dairy farms. Already in the 1970s, regulations were introduced limiting maximum stocking rate of animals per area, and in 1999 only 5% of the specialized dairy farms had more than 2.3 LSU ha^{-1}. During the last 10-15 years detailed, public regulations have been introduced and continuously tightened. In the early 1990s mandatory slurry storage capacity was extended to a minimum of 6-9 months, and later restrictions for imported mineral fertilizer have been introduced. For a more detailed description of these regulations, see part I of the Danish country report.

Since 1950, pilot farm studies have been part of applied agricultural research in Denmark. The Danish Institute of Agricultural Sciences monitors 30-40 mixed dairy farms per year and prepares technical-economic reports on livestock and field production, animal welfare and environmental impact. Farms with pig production, organic dairy, organic egg, organic pig and organic arable production have been included, and the environmental aspects, especially concerning N flows between field and herd have become primary focus areas. On the pilot farms the flow of feed and nutrient from field to herd has been measured, and internal N balances of fields and groups of animals have been measured and published, see Table 6. From 1996 onwards, the central advisory organisation has been involved in data recording and reporting.

The private pilot farmers were selected to be progressive and interested in cooperation with experts. The farms have been larger than average, partly because “future” farms were chosen to ensure that the data could be used for the development of the total dairy sector in Denmark. Advisors, farmers, and other stakeholders have regarded the results as representing typical and relevant farms. Lately, the demand for comprehensive descriptions of resource use and environmental impacts from major farm types in question (dairy, pig and arable) has generated a need for statistically representative farm models based on an average management level. Technical-economic data based on Danish farm accounts are available from a group of farms representing the major agricultural sectors in Denmark with the actual production and management level. This publication describes the Danish method of nutrient accounting using data from dairy pilot farms and representative technical-economic data for the total dairy sector in Denmark.

Objective

The objectives of this paper are

- to characterise Danish dairy farms in terms of production, size and crop-livestock interactions,
- to compare N surplus from different dairy systems especially organic vs. conventional production,
- to present data on nutrient cycles and farm N surplus for Danish dairy farms in comparison with other Danish farm types,
- to demonstrate the use of pilot farms in combination with models of typical farms based on representative technical-economic accounts as a method for the quantification of nutrient losses and the potential for improvements.

We intend to present analyses of N flows and surpluses from four independent data sets, three of which are based on different groups of pilot farms and one based on a large, representative sample of farm accounts. On the basis of these data, it is demonstrated how relatively simple assumptions allow modelling of farm N flows and breakdown into herd and crop sub-systems. From this it is possible to estimate emissions and losses that allow for comparisons between different systems and projections of developments of typical dairy systems in the near future.

Methods

All Danish farms are obliged to keep detailed records of purchases and sales for tax purposes and the yearly accounts are made with professional help. A representative set of these accounts, 2239, are reported by the advisors to the Danish Research Institute of Food Economics (DRIFE) and constitute the basic empirical input to the representative farm types presented here. Besides the economical data, information on land use, livestock numbers and amounts of produce are included in the data set compiled by the advisors. The modelled representative farm types were based on 1999 farm accounts, sampled as to represent the total Danish agricultural sector for the main livestock and crop production. The data are described in detail on the homepage www.lcafood.dk. The same overall method was used in the years 1995-1996 (Halberg et al., 1999). Table 1 shows the number of accounts used for the models and which farm parameters were found directly from the accounts. The modelled representative farm types were compared with data from 83 pilot farms. Pilot farms were monitored during the years 1989-2003 by longitudinal survey techniques as described at http://www.agrsci.dk/jbs/bepro/concept%20pdf%20format.pdf. Pilot farm results were used for comparisons with model farms and for demonstrating the variation around the average N surplus.

In the Danish dairy sector, biological fixation is an important N input, especially on organic farms. On pilot farms, fixation in grass/clover was calculated by the method presented by Kristensen et al. (1995). For the representative farms, the fixation and mineral fertilizer for grass/clover was assumed to be the same level as on the pilot farms. Details of the level of fixation in grass/clover and information regarding fodder, N demand, crop yield estimates and fertilizer use are given in the Appendix. The ammonia and denitrification losses shown in Tables 3-5 were calculated using the methods of Poulsen and Kristensen (1998), Andersen et al. (1999), Illerup et al. (2002) and Vinther and Hansen (2004) respectively.

Farm balances were calculated following the principles described in Halberg et al. (1995) and further developed by Sveinsson et al. (1998) and Kristensen (2002).Coherent N balances at farm level were calculated, incorporating imports of fodder (cereal and concentrates) and mineral fertilizers and exports of milk, meat, cash crops and surplus manure. Summarizing and up scaling key in- and outputs across representative farm types showed good agreement with national statistics of land use, livestock numbers, average yield per crop, input of fodder concentrate and fertilizer per crop. The fertilizer was adjusted 8% in the farm models to account for the national level consumption.

The sample represents 4% of the conventional farms and 18% of the organic farms in Denmark (Table 1). Seventy-five percent of the dairy cows are on sandy soil, mostly in western Jutland. The dairy farm types cover 23% of the agricultural land and include 75% of all dairy cows (Data not shown). The average herd size on conventional farms is 61 cows and 82 cows on organic farms. The average stocking rate on conventional farms is 1.46 LSU ha^{-1} and 1.28 on organic farms. Eighty-five percent of the farm area is part of a crop rotation. Twenty-six percent of the farm area of conventional farms is grass/clover. This percentage on organic farms is twice as large. The remainder of the rotating area is mainly under cereals, partly for grain and partly for whole crop silage harvested 2-3 weeks before full ripe. Maize for silage has become important, mainly on conventional farms. Cereal grain yield is 5.2 t ha^{-1} on conventional farms and 19% lower on organic farms. Roughage yields are assumed to be on the average level of pilot farms, and the average yield of rotating crops is 5,700 SFU ha^{-1} = 6,300 kg DM ha^{-1} on conventional dairy farms and 21% lower on organic farms.

The milk yield level in 1999 was 7,373 kg ECM milk cow^{-1} $year^{-1}$ on conventional farms and 7% lower on organic farms. Of the total SFU-intake by cows, 54% is home-grown roughage on conventional farms and 63% on organic farms. An average level of protein was 18.3% of SFU = 20% of DM.

Summation within the following tables may not always give the exact sum, due to rounding errors.

Table 1:

Results and discussion

Dairy farm N balances

Table 2 shows the farm N balances. On organic farms, fixation constitutes app. 50% of the total N input. On conventional farms, imported fertilizer and fodder together account for app. 75% of the total N input. But on farms with stocking density below 1.4 LSU ha^{-1} fertiliser input alone accounted for 50% of total N-input and feed 25%, while it was vice-versa on the high stocking density farms. On conventional farms, the weighted average N surplus is 184 kg N ha^{-1}, which is 63 kg higher than the average for organic farms. The conventional farm types with high stocking density have higher N-surplus than the two low-density farm types. This is in accordance with an analyst of the effect of stocking rate on N surplus on the 38 pilot farms (Nielsen and Kristensen, 2005). The data from pilot farms show that the farm gate N surplus strongly correlates with stocking rate (Fig. 1).

Using the stocking rate corrected for import and export of manure it can be shown that N surplus at the dairy farms increased significantly with increasing stocking rate but not in a way that differed significantly between conventional and organic dairy farms. The average effect of stocking rate on farm N surplus was 78 kg N ha^{-1} per LSU. At the same stocking rate, the N surplus of organic pilot farms was 48 kg lower than that of conventional farms. In Fig. 1, the average (1997-2003) farm gate N surplus for each farm is shown for comparison with the modelled farm types. The modelled farm types closely fit the average of the pilot farms.

Table 2:

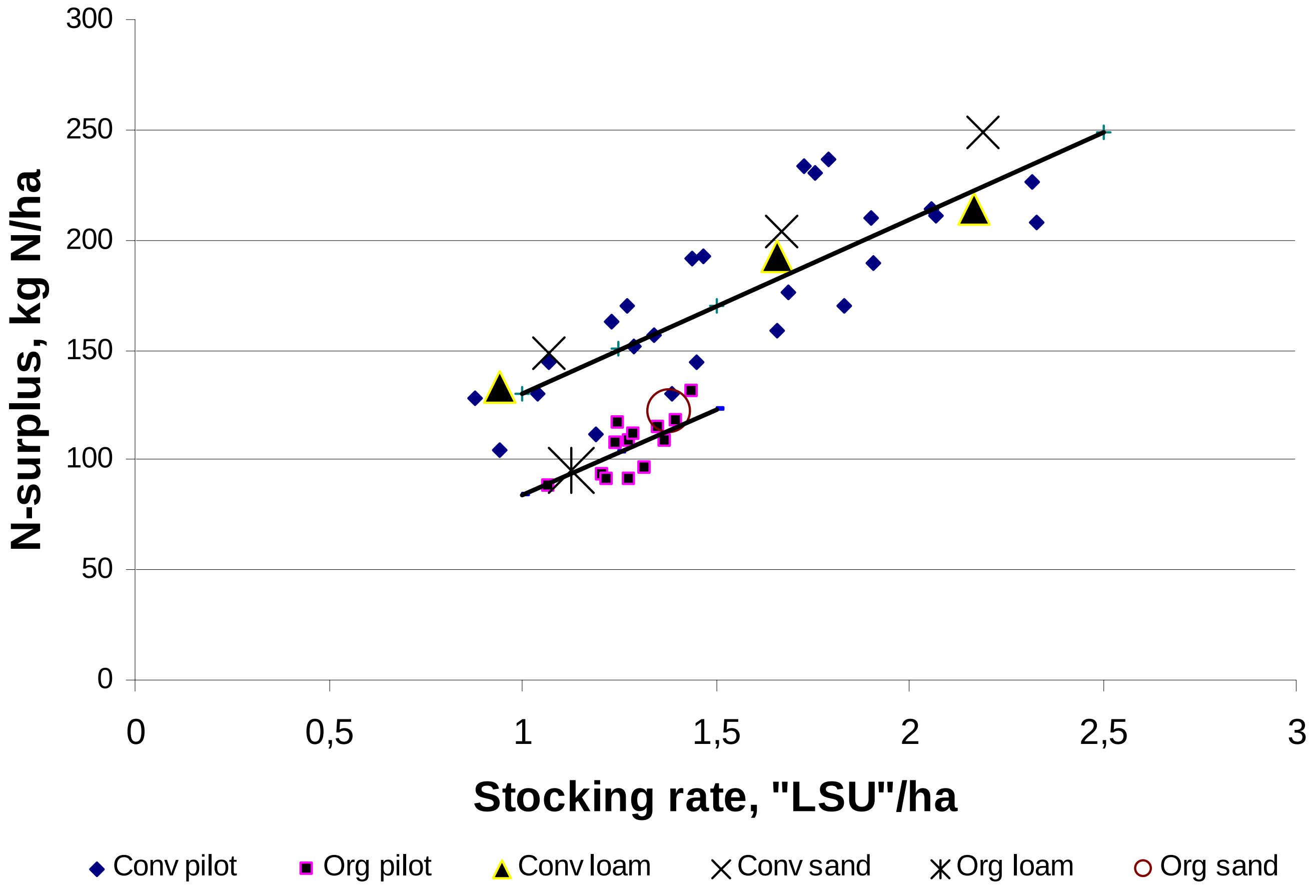

Figure 1. Farm N surplus on specialized Danish dairy farm types in 1999, see Table 2, and on pilot farms (one point is average per farm for the years 1997-2003) as a function of stocking rate, corrected for import/export of animal manure (100 kg N = 1 LSU). Lines are average pilot farms, see Nielsen and Kristensen (2004).

A sensitivity analysis was conducted to check the effect of assumptions on the results, see Table 2. Farm balances were calculated with 25% higher fixation, 10% lower N efficiency in feeding (= higher N content in imported feed), 10% higher protein content in roughage, and 10% higher net yield in roughage, respectively, and all other parameters unchanged. The analysis changed the farm gate N balance 2-20 kg N ha^{-1}, with the largest changes on organic farms as a result of the higher percentage of home-grown roughage. Increasing the fixation by 25% decreases the difference between conventional and organic dairy production by 13 kg N ha^{-1} (the difference between 7 and 20 kg increased N surplus on average conventional farms and organic farms). Also higher yield from fields decreased the demand for imported feed more on the organic farms and 10 % higher yield decreased the import by 8 kg N ha^{-1} more on the organic farms compared with the conventional farms with higher overall import. The other sensitivities only change the difference between conventional and organic types by 2-4 kg N ha^{-1}.

Dairy N-balances at the herd and field level

Tables 3 and 4 show the coherent herd and field N-balances, which together represents the within farm N-flow, summing up to the overall farm gate N-balance. In Table 3, the herd balance is shown both from the representative data and as the average result from dairy pilot farms on sandy soils. The representative farm types all have a herd input around 150 kg N LSU and a milk yield of 23-25 kg N LSU^{-1} resulting in almost identical surplus of 118 kg N LSU^{-1}. The reason for this is that the cows protein intake was modelled using a standard 20% N – use herd efficiency. However, the modelled herd balances fit well with the average of pilot farms (122 kg N surplus). On the pilot farms, the N-input with roughage is lower than for the representative farm types, especially during grazing. This is due to a lower N-uptake in grazed grass/clover. N-output in manure is greater on the pilot farms. This makes the animal manure input into the fields and the field N-surplus higher on the pilot farms. The between-farm variation on the pilot farms is also presented in Tables 3 and 4. This gives an indication of the scope for improvements in N-use efficiency. The CV (Coefficient of Variance) of the herd balance on conventional pilot farms was 8% (10 divided by 122) and 14% on the organic farms. This is mainly a consequence of lower N-intake during grazing on the conventional farms, which means that N-intake is more easily adjusted with imported feed. On organic farms, Danish-produced conventional rapeseed cake is the dominating concentrate fodder import, which gives a high herd N-surplus, especially during the grazing season. The herd N-efficiency varies between 19-22%, with no systematic difference between conventional and organic.

Table 4 shows that while the N-production in manure per LSU^{-1} is almost identical for the dairy farm types, the manure N supplied per ha is not surprisingly – higher in the farm type with 1.7 LSU^{-1} than farm type 1.0 LSU^{-1}, the 84 kg N LSU^{-1} in animal manure from storage (Table 3) equals an average input of 140 kg N ha^{-1} on the fields on farm type 1.4-2.3 LSU ha^{-1}. This corresponds to app. 50% of total N supplied to the crops. The field level N-surplus of 134 N kg per ha on the low stocking rate type plus the ammonia loss in stables and storage (and denitrification – (12+2) * 1.1 LSU ha^{-1} – corresponds to the farm gate balance of 149 kg N ha^{-1} in Table 2.

The CV of the field balance on conventional pilot farms is 23%, and for organic this is 15%. There is a large variation between the lowest and highest N-surpluses and possibilities for lowering the N-surplus are numerous. The organic dairy farms realize 54-60% field N-efficiency and the conventional dairy farms 43-49%. On farms with a low efficiency, there should be good possibilities to improve the N-utilization.

Table 3
Table 4
Table 5

Distributing dairy N-surpluses between losses

The field N-balance in Table 5 was calculated by subtracting the ammonia loss and denitrification in animal housing and manure storage from the farm surplus and corresponds to the detailed balance in Table 4. Organic farms more often than conventional farms tend to have deep litter systems, so losses of ammonia during storage will be higher. However, extra conventional straw is imported and ammonia losses during spreading are smaller than for slurry-based systems, so the total losses are calculated to be a similar proportion of the manure N flow. The average field N-balance on conventional dairy farms was 161 kg N ha^{-1}. The ammonia losses during spreading were assumed to be 8 % of the manure N applied, see appendix for details of gaseous N-losses. The remaining surplus (e.g. 126 kg N on conventional average) includes the soil-N changes and leaching.

Partitioning the remaining field surplus between changes in soil-N and leaching is difficult. There is no reason to believe that there should be any major systematic difference between conventional and organic dairy farms in changes of the soil-N pool. Conventional has a lower proportion of grass/clover in the crop rotation but a higher stocking rate, compared to organic, probably resulting in about the same organic matter input on the two farm types. Therefore, the difference in field balance of around 60 kg (102 in organic vs. 161 in conventional) probably corresponds with an identical difference in leaching. The calculated leaching was 50 kg N ha^{-1} lower from organic dairy farms compared to conventional milk production.

A preliminary attempt at partitioning the remaining field N-surplus between changes in soil-N and leaching is shown in Table 4 and 5. The method used will be described at www.agrsci.dk/c-tool. There is a tendency towards higher leaching losses on sandy farms, as expected. However, although there is an increase in the farm surplus with increasing stocking rate, this is accounted partly by higher gaseous losses (ammonia volatilisation and denitrification) and partly by higher N-leaching.

Estimating leaching as the difference between farm gate surplus and gaseous emissions implies that any errors in the surplus and gaseous emissions will assemble in that estimate. An alternative method is needed, but so far, no simulation model can reliably predict leaching for dairy farms with grazed grass/clover pasture. Leaching measurements made in Denmark under organic cattle trials with continuous grazing for 8 years of grass/clover and with nutrient removal from the grazed area only via milk and meat, resulted in a maximum leaching of 5-60 kg N ha^{-1}, measured in the winter in year 7-8. Leaching values of <10 kg N ha^{-1} were recorded in unfertilised grass/clover, while leaching from pure grass fertilised with 300 kg N ha^{-1} was around 65 kg N ha^{-1} year^{-1} in year 7 and 8 (Eriksen et al. 2004). Results from other organic crop rotation trials also show an average leaching of around 40 kg N ha^{-1}, although higher losses have been measured after green mulching at sandy soils (http://www.agrsci.dk/pvj/plant/croprot/resultuk.shtml).

The lower leaching from organic farms compared to conventional farms could be explained by the crop rotation on organic farms, with around 50% of the area under grassland and with organic grass/clover being more N-efficient than conventional, N-fertilized grass/clover. The latter is the consequence of the substitution rate between N-fertilizer and fixation, where 1-2 kg extra N-fertilizer lowers fixation by 1 kg N ha^{-1} (Kristensen and Kristensen, 2002). Also a better utilization of nitrogen in urinated grass/clover patches gives higher N-utilization (Hutchings and Kristensen, 1995).

Emissions of greenhouse gases from representative farm types.

Table 5 shows N-balances and greenhouse gas emissions of the main farm types in Denmark and the Danish average. Relative to dairy farms, pig farms have a larger external N exchange of both fodder and meat production and a higher ammonia loss from stables and manure storage. Emissions of CO_2 only include emissions from combustion of fossil fuel on farms. Organic dairy farms have a lower CO_2 emission than the conventional equivalents, due to lower use of fossil fuel per hectare, because of a greater grassland area. Emissions of greenhouse gases (calculated in CO_2 equivalents) are higher for farms with livestock than for those without. Emissions are higher for dairy farms than for pig farms, because of the contribution of enteric fermentation to methane emissions.

The emission per kg of milk has been calculated using LCA methodology, showing only small differences between farms with different stocking rates (www.lcafood.dk).

Changes in dairy N balances over time

Changes in N-balances over time, based on additional datasets from the pilot farms, are given in Table 6. It appears that the farm N surplus on conventional farms has been reduced by 30% over the last 10 years, whereas the surplus on organic farms has fallen only slightly (but not identical farms in the three pilot farm samples). The reduction in cow dairy farm surplus appears to have happened during the first half of the 1990'ties (coinciding with the implementation of manure use regulations). Note that conventional and organic farms cannot be compared directly here, as they have different stocking rates. In the bottom line the LSMEANS estimates for difference at same stocking rate is shown. The results from pilot farm investigations fit very well with the modelled data from representative farms.

The progressive implementation of the Water protection plan (VMPII) Hutchings et al., 2003 is expected to result in a further decrease in N losses (Hutchings et al., 2003). A forecast in the year incorporating VMPII is shown in Table 7. The conventional representative farms has improved 26 kg N ha^{-1}, from 184 to 158 kg N ha^{-1}, and the organic farms has the same level = 122 kg N ha^{-1}. On the relatively few pilot farms the conventional farms showed the same decrease as the representative farms, but the organic farms in year 2003 only had n farm gate N-surplus on 98 kg N ha^{-1} (LSMeans estimate, see Nielsen and Kristensen (2005)). The reason for the lower farm gate N-surplus was mainly reduced import of artificial fertilizer on the conventional farms and reduced fodder import on the organic farms in order to fill in a new regulation of 100 % organic feed from year 2001. A typical response of organic dairy farms has been the substitution of rape cakes by concentrates with a higher proportion of cereals.

Comparison of environmental impact between farm types

While the arable farm types on both sandy and loamy soil have N surpluses below 100 kg N ha^{-1}, the pig types show a farm N balance of around 140 kg N ha^{-1} with 1.5 - 1.6 LSU ha^{-1}. The field surplus was 161 kg N ha^{-1} on dairy compared with 75 and 105 on average arable and pig farms (Table 5). However, it cannot be assumed that soil N changes are the same in these systems. To illustrate the possible combined effect of field N surplus and soil N change in these different systems, a preliminary model was used to predict net mineralization. Because of the high input of organic material and grass/clover on dairy farms, the model predicted an accumulation of 7-39 kg N ha^{-1} year^{-1} on dairy farms compared with steady state on pig and arable farms (Table 5). Thus, due to low input of organic matter, the modelled leaching from pig farm models was 20 kg N ha^{-1} lower than dairy farms, and arable farms with only 53 kg N ha^{-1} in N-leaching. The overall average change in soil-N across soil types and farm models was an increase of 8 kg N ha^{-1}. This may be a bit too high, since Heidmann et al. (2001) found no overall change during a ten year period in 300 samples representing Danish farming systems. But the national balances used for assessing the effects of Water Project schemes estimated 62 kg N ha^{-1} leaching and residual and soil build up corresponding to 11 kg N ha^{-1} (VMPII). The combined result of our representative farm types scaled to national level using the weights behind each farm type is in accordance with the VMPII report. However, changing the mineralization parameters in the model will probably not change the relative soil-N change between pig and dairy. Nitrate leaching was measured in 1996-2000 in about 40 fields and amounted to 94-98 kg N leaching ha^{-1} (Grant et al., 2000). The measurements were extrapolated to the whole Danish territory with standard precipitation. The overall modelled N-leaching in Denmark in 1999 was around 75 kg N ha^{-1} (Grant et al., 2000). Thus, if no overall change in soil-N is assumed, then the model based on the representative sample gives the same level of N-leaching (100 – 23 = 77 kg N per ha).

Table 6
Table 7

Conclusion

A large group of representative dairy farms in 1999 has been used to calculate farm N surpluses. Both investigations on pilot farms and representative farms have shown the same overall result. The conventional dairy farms have an increase in farm surplus of 78 kg N LSU^{-1} in the interval of 0.8–2.5 LSU ha^{-1}. Organic dairy farms have consistently 44–63 kg lower N surplus than conventional farms since 1994. The strength of this conclusion is that the underlying data represent realistic management situations. This is especially relevant for cattle farms, because the large internal flows on these farms are difficult to quantify, so that it is difficult to accurately calculate field level balances directly from field input and outputs. It is very important that each farm is analysed as an entity, where interaction between management, agricultural production (herd and crops) and N-losses can be analysed at the farm level.

Farm N surplus is an expression of the long-term potential losses. If changes in soil-N are assumed to be similar on both organic and conventional dairy farms, then nitrate leaching at equal stocking rate is about 50 kg N ha^{-1} less on organic farms than on conventional dairy farms in year 1999. In 2002 the difference has decreased to around 25 kg N,

The data from organic mixed dairy farms production have been used as an extreme case, to demonstrate the capacity of unfertilised grass/clover to reduce farm N-surplus. Using this knowledge in models of conventional farms shows there is also scope to reduce the farm N-surplus in these systems. It is likely that the lower farm N surpluses for organic systems are due to the inclusion of unfertilised grass/clover, combined with the use of cereals on about 50% of the land area, to utilise the carry-over of N from the grass/clover pasture.

Losses of nitrate, ammonia and nitrous oxide from livestock farming appear to be higher than for arable farming. Increases of nitrate leaching with increasing livestock density in Denmark are lower than increases of farm N surpluses. This is because a relatively higher proportion of the extra surplus is lost in gaseous form.

Our analysis shows that the combination of pilot farms and representative farms is a relevant tool for predicting agronomic, economic and environmental effects on farm and regional scale of different farm types and interventions. As demonstrated in Fig. 1, the pilot farms show differences between farms with comparable soil types and stocking rates (variation around average line). To the extent that these differences can be explained by differences in management, including the farmer’s choice of crop rotation and feeding systems, the farm variation may be used to generate ideas and benchmarks for improvement of farms with high surpluses. The farm models generated from the representative sample allow for the generalisation of average farms within the selected groups, for calculation of other emissions in a standard Life Cycle Assessment framework and for scaling up to national emission and N surplus levels. Thus, these methods combined could be powerful tools in the search for improvements and for the evaluation of proposed regulations and interventions in dairy farm nutrient management.

Table 1. Characteristics of representative specialised Danish dairy farms in 1999.

	Unit	Measured(M) Calculated(C) Estimated(E)	Sandy (< 5% clay) Conventional LSU < 1.4	Sandy Conventional 1.4-2.3	Sandy Organic	Loamy (5-15 % clay) Conventional LSU < 1.4	Loamy Conventional 1.4-2.3	Loamy Organic	Average Dairy Conv	Average Dairy Org	Average Pig	Average Arable	Average DK
Farm type[3]													
Farms in population	Number of farms	C	1912	4004	695	432	849	115	7794	810	7310	7706	43570
Farms in dataset	Number of farms	M	83	182	125	23	32	24	350	149	476	318	2073
Agricultural area	1000 ha in DK	M	156	261	69	43	43	10	530	81	587	732	2523
Herd													
Number of cows	Cows/farm	M	48	67	84	56	55	62	61	82	0	3	13
Number of LSU[3)]	LSU/farm	M	81	109	131	87	84	100	99	128	111	17	48
Area													
Farm area	Ha/farm	M	81	65	99	100	50	88	68	100	70	82	51
Permanent grass	Ha/farm	M	7	6	8	8	3	9	6	9	1	1	3
Set aside	Ha/farm	M	6	4	5	6	2	5	4	5	5	7	4
Cereal for harvest	Ha/farm (%)[1)]	M	33(49)	12(23)	14(16)	45(56)	16(38)	21(29)	20(34)	15(17)	50(79)	49(66)	27(61)
Maize & whole crop	Ha/farm (%)[1)]	M	13(20)	22(41)	29(34)	15(19)	13(31)	20(28)	18(32)	28(31)	0(0)	1(1)	4(9)
Grass/clover in rotation	Ha/farm (%)[1)]	M	13(20)	16(30)	39(47)	12(15)	12(27)	28(39)	14(26)	40(44)	1(1)	1(2)	5(10)
Stocking rate	LSU/ha farm area	M	0.99	1.67	1.32	0.88	1.66	1.13	1.46	1.28	1.59	0.21	0.93
	LSU/ha cultivated[2)]	M	1.21	2.05	1.48	1.06	1.91	1.31	1.76	1.41	1.76	0.23	1.07
Field production													
Cereal	100 SFU/ha	M	52	49	41	56	54	44	52	42	59	64	57
Tot 100 SFU ha^{-1}cultivated	100 SFU/ha	C	55	57	44	55	58	44	57	45	52	55	54
Avr. protein in total fodder	% protein of SFU	E	13.6	14.9	17.4	13.3	14.8	16.2	14.3	17.0	11.2	10.6	11.8
Animal production													
Milk yield	Kg ECM cow^{-1} $year^{-1}$	M	7431	7429	6866	7227	7288	6811	7373	6860	-	7354	7305
Fodder requirement													
SFU/LSU, in total	SFU/LSU	E	4768	4768	4468	4844	4781	4406	4774	4461	4622	4807	4555
-in roughage	SFU/LSU	E	2802	2721	2841	2620	2250	2676	2568	2823	42	767	1306
-in grain	SFU/LSU	M	1217	1210	1227	1446	1646	1330	1347	1272	3252	2938	2262
Avr. protein in total fodder	% protein of SFU	E	18.4	18.3	18.2	18.3	18.1	18.3	18.3	18.2	16.2	-	-

[1)] % of area in rotation.

[2)] On organic farms set aside is included in the cultivated area, on conventional farms the set aside is assumed not cultivated.

[3)]Livestock units per ha. 1 LSU = 0.85 Holstein dairy cow at 8,500 l milk cow^{-1} $year^{-1}$.

Table 2. Farm gate N-balances of representative specialised Danish dairy farms in 1999. Kg N ha^{-1} year^{-1}

	Sandy (< 5% clay)			Sandy loamy (5-15 % clay)			Average				
Farm type:	Conventional		Organic	Conventional		Organic	Dairy		Pig	Arable	DK
	LU < 1.4	LU 1.4-2.3		LU < 1.4	LU 1.4-2.3		Conv.[1)]	Org			
Inputs Avr. LSU ha^{-1}	1.0	1.7	1.3	0.9	1.7	1.1	1.5	1.3	1.6	0.2	0.9
Mineral fertilizer	104	95	0	103	83	0	95	0	83	118	98
Fixation	23	34	78	21	35	68	29	76	4	5	15
Manure import	9	10	16	6	9	7	4	15	0	9	3
Supplement feed	46	105	51	42	109	42	91	50	194	14	84
Precipitation	16	16	16	16	16	16	16	16	16	16	16
Total input	198	260	160	189	252	132	236	156	296	162	216
Outputs											
Milk	-23	-40	-28	-21	-41	-24	35	-28	0	-1	-10
Meat	-8	-10	-6	-8	-10	-6	-10	-6	-99	-10	-36
Cash crops	-18	-4	-2	-27	-8	-7	-11	-2	-39	-71	-41
Manure export	0	0	0	0	0	0	-3	0	-20	0	0
Total output	-49	-55	-36	-55	-59	-36	-53	-36	-158	-83	-86
Farm gate N-balance	**149**	**206**	**124**	**134**	**193**	**96**	**184**	**121**	**138**	**79**	**130**
Sensitivity on N-balance											
- by 25% higher N-fixation	+6	+9	+20	+5	+9	+18	+7	+20	+1	+1	+4
- by 10% lower N-efficiency	+7	+14	+8	+7	+13	+10	+11	+10	0	0	+3
- by 10% higher N in roughage.	-6	-10	-9	-7	-11	-11	-9	-11	-4	-1	-4
- by 10% higher yield from field	-5	-3	-10	-4	-2	-12	-3	-11	-8	-8	-6

1) Average includes farms with more than 2.3 LSU ha^{-1}. Data presented of www.LCAFood.dk>processes>agriculture.

Table 3. Herd N-balance on representative specialised Danish farms in 1999 and pilot farms in 1997-2001. All data in kg N LSU^{-1} $year^{-1}$.

	Dairy on sandy (< 5% clay)					Dairy on loamy (5-15% clay)			Dairy				
Farm type:	Conventional, repr.		.	Organic		Conventional, repr.		Organic,					
	LSU<1.4	1.4-2.3	Pilot[3]	Repr.	Pilot[3]	LSU < 1.4	1.4-2.3	repr.	Conv	Org.	Pig	Arable	DK
Avr. LSU ha^{-1}	1.0	1.7	1.6	1.3	1.1	0.9	1.7	1.1	1.5	1.3	1.6	0.2	0.9
Inputs Conserved roughage	44	44	50	55	65	42	37	51	42	54	1	12	20
Grazing	30	26	37	31	58	28	23	30	25	31	1	11	14
Concentrates	46	50	52	25	21	48	52	26	50	23	79	67	75
Imported cereals	0	13	16	14	16	0	14	12	11	14	43	0	23
Home-grown cereals	20	7		6		24	13	10	11	6	27	56	21
Straw & imported animals	11	9	-[4]	8	-[4]	10	9	9	10	8	9	14	10
Total input	151	149	155	138	160	151	149	138	149	138	161	159	164
Outputs													
Milk	-23	-24	-27	-22	-26	-24	-25	-21	-24	-22	0	-6	-10
Meat	-8	-6	-6	-4	-6	-9	-6	-5	-7	-4	-62	-48	-42
Total output	-31	-30	-33	-26	-32	-33	-31	-26	-31	-26	-62	-54	-52
Herd N-balance	**120**	**118**	**122**	**112**	**128**	**118**	**118**	**111**	**119**	**111**	**98**	**105**	**112**
Standard deviation on N-bal.			10		18								
Animal manure left during grazing	-23	-19		-23		-20	-17	-23	-19	-23	-1	-8	-11
Amm. loss, stable & storage	-12	-13		-11[1] to –17[2].		-9.	-10.	-8[)] –14[2]	-13	-11	-20	-17	-18
Denitrification, solid manure	-2	-2		-3		-2	-2	-3	-2	-3	-1	-2	-2
Animal manure from storage	-82	-84		-63 to -74		-83	-86	-74	-86	-74	-77	-78	-79
N-efficiency, herd, %	**20**	**20**	**21**	**19**	**20**	**22**	**21**	**19**	**21**	**19**	**39**	**34**	**32**
Standard deviation on N-eff			**1.4%-units**		**1.8%-units**								

[1]Same losses as conventional dairy systems (23% deep litter, 77% slurry and 10% solid and liquid manure)
[2]50% deep litter, 40% slurry and 10% solid and liquid manure.
[3]Pilot farms, average of 1997-2001.
[4]Included in meat output.

Table 4. Field N-balance and N-loss on representative specialised Danish farms in 1999 and pilot farms in 1997-2001. Kg N ha^{-1} $year^{-1}$.

	Dairy on sandy (< 5% clay)					Dairy on loamy (5-15% clay)			Dairy		Pig	Arable	DK
Farm type:	Conventional, repr.			Organic		Conventional, repr.							
	LSU<1.4	1.4-2.3	Pilot[5)]	Repr.	Pilot[5)]	LSU< 1.4	1.4-2.3	Organic	Conv	Org.			
Av. LSU[7)]ha^{-1}	1.0	1.7	1.7	1.4	1.3	1.0	1.7	1.2	1.5	1.4	1.3	0.4	1.0
Inputs Anim. manure from storage	89	140	195[8)]	105[1)]-114[2)]	160[8)]	79	142	83[1)]-93[2)]	124	102	94	28	75
Animal manure during grazing	23	32		30		18	28	26	27	30	1	2	10
Mineral fertilizer	104	95	92	0	0	104	83	0	95	0	83	118	99
Fixation	23	34	37	78	76	21	35	68	29	76	4	5	14
Precipitation	16	16	16	16	17	16	16	16	16	16	16	16	16
Total input	255	317	343	228[1)]-236[2)]	253	238	303	193[1)]- -203[2)]	291	224	198	169	215
Outputs													
Conserved roughage	-44	74	-81	-72	-69	-37	-62	-58	-61	-70	-1	-2	-19
Grazed	-30	-43	-61	-40	-61	-25	-38	-34	-36	-39	-1	-2	-14
Home-grown cereals	-29	-15	-15	-9	-10	-29	-29	-14	-23	-10	-70	-65	-52
Cash crops	-18	-4		-2		-26	-8	-7	-11	-2	-21	-25	-16
Total output	-121	-137	-157	-123	-140	- 117	-137	-114	-130	-122	-93	-94	-101
Field N-balance	**134**	**180**	**186**	**106[1)]to114[2)]**	**113**	**121**	**166**	**79[1)] to 89[2)]**	**161**	**102**	**105**	**75**	**114**
Standard deviation, field N-bal.			**42**		**16**								
Amm. loss spreading	-10	-15		-9[1)] to -5[2)]		-10	-14	-7[1)] to –4[2)]	-13	-9	-11	-6	-9
Amm. loss during grazing	-2	-2		-2		-1	-2	-2	-2	-2	0	0	-1
Amm. loss crops	-4	-4		-2		-4	-4	-2	-4	-2	-5	-5	-4
Denitrification, field	-12	-15		-12 to –11		-34	-34	-32 to –31	-17	-14	-13	-11	-13
Soil-N changes [9)]	25	39		36[3)] to –41[4)]		7	24	15[3)] to –22[4)]	31	34	1	0	8
Nitrate leaching estimated by diff.[6)]	-81	-105		-45 to –64		-65	-88	-21 to –42	-94	-41	-75	-53	-79
N-efficiency, field, %	**47**	**43**	**46**	**54 to 56**	**55**	**49**	**45**	**59 to 61**	**45**	**54**	**47**	**56**	**47**
Standard deviation, field N-eff.			5%-units		5%-units								

[1)]Same losses as conventional dairy systems (23% deep litter, 77% slurry and 10 % solid and liquid manure)

[2)]50% deep litter, 40% slurry and 10% solid and liquid manure.

[3)]Same soil-N changes as conventional dairy systems.

[4)]25% lower crop residues in grass/clover and 25 % higher C-input from deep litter.

[5)]Data from pilot farms 1997-2001.

[6)]Leaching = field N-balance – amm. loss – denitrification +/-soil-N changes. For example organic dairy on sand: 106 –9 –2 -2 –12 +36 = 45 kg N ha^{-1}.

[7)]Inclusive correction for manure import, 100 kg N-import = 1 LSU.

[8)]Inclusive manure deposited directly on grazed fields.

[9)] Calculated with c-tool, see www.agrsci.dk/c-tool

Table 5. Estimated environmental losses on representative specialised Danish farms in 1999.

	Sandy (< 5% clay)			Loamy (5-15 % clay)			Average				
Farm type:	Conventional dairy		Organic	Conventional dairy		Organic	Dairy		Pig	Arable	DK
	LSU < 1.4	1.4-2.3	dairy	LSU<1.4	1.4-2.3	dairy	Conv	Org			
	kg N ha^{-1} year^{-1}										
Farm gate N-balance	**149**	**206**	**124**	**134**	**193**	**96**	**184**	**121**	**138**	**79**	**133**
Gaseous N-loss stable & storage	-15	-24	-18	-13	-25	-15	-22	-18	-33	-4	-19
Field N-balance	**134**	**180**	**106**	**120**	**165**	**79**	**161**	**102**	**105**	**75**	**114**
Amm. loss animal manure & min. fert	-12	-17	-11	-11	-16	-9	-15	-11	-9	-6	-10
Amm. loss, crops	-4	-4	-2	-4	-4	-2	-4	-2	-5	-5	-4
Denitrification, field	-12	-15	-12	-34	-34	-32	-17	-14	-13	-11	-13
Soil-N changes[1)]	25	39	36	7	24	15	31	34	1	0	8
N-leaching estimated by difference[2)]	**-81**	**-105**	**-45**	**-65**	**-88**	**-21**	**-94**	**-41**	**-75**	**-53**	**-79**
	Different units										
Emissions[3)] Methane, kg CH_4 ha^{-1}	113	189	141	101	181	121	164	139	39	12	62
N_2O (ICCP), kg N_2O ha^{-1}	11	14	9	9	13	7	13	8	8	6	8
Ammonia, kg NH3 ha^{-1}	35	51	28	32	51	28	46	33	57	18	38
CO_2, kg CO_2 ha^{-1}	458	526	392	471	530	397	508	393	447	427	437
Global Warming Potential, ton CO_2 equiv ha^{-1}	6.1	8.9	6.0	5.5	8.5	5.0	7.9	5.9	3.7	2.5	4.3

[1)] Soil-N changes calculated with C-tool, see www.agrsci.dk/c-tool/

[2)]Leaching = field balance – amm. loss – denitrification +/- soil-N changes. For example organic dairy on sand:106-11-2-12-36=45 kg N ha^{-1}.

[3)] See on www.LCAFood.dk

Table 6. Farm gate N-turnover on representative specialised Danish dairy farms. Kg N ha^{-1} $year^{-1}$.

		Conventional					Organic				
	Year	1989-90[3]	1994-97[4]	1997-2003[6]	1999-2002[7]	1999[5]	1989-90[3]	1994-97[4]	1997-2003[6]	1999-2002[7]	1999[5]
	Number of farms	16	5	25	87	350	14	10	13	42	149
	Avr. LSU ha^{-1}	1.76	1.70	1.54	1.52	1.46	1.24	1.26	1.14	1.21	1.3
Inputs	Fertilizer	161	100	86	80	95	0	0	0	0	0
	Fixation	29	45	27[1]	33[1]	29	87	89	78[1]	95[1]	76
	Manure import	0	0	34	17	4	9	14	25	17	15
	Supplement feed	77	129	115	114	91	39[2]	47	38	50	50
	Precipitation	16	16	16	19	16	16	16	16	17	16
	Total input	**283**	**290**	**278**	**264**	**236**	**151**	**166**	**157**	**179**	**156**
Outputs											
	Milk	-47	-39	-42	-41	-35	-32	-28	-28	-31	-28
	Meat		-18	-9	-9	-10		-6	-6	-6	-6
	Cash crops	0[2]	-22	-19	-22	-11	0[2]	-4	-1	-3	-2
	Manure export	0[2]	-21	-29	-16	-3	0[2]	0	-6	-11	0
	Total output	**-47**	**-101**	**-99**	**-88**	**-53**	**-32**	**-38**	**-41**	**-51**	**-36**
Balance		**240**	**173**	**177**	**176**	**184**	**124**	**112**	**116**	**128**	**121**
	Standard deviation	52	50	43	51		19	35	23	35	
	Difference to conv						-116	-61	-61	-48	-63
Difference on same stocking rate							-85	-61	-57		-44

[1]Calculated after Kristensen et al. (2003)
[2]Crops for sale and manure is deducted import
[3]Halberg et al. (1995)
[4]Halberg (1999).
[5]Table 2
[6] See Nielsen and Kristensen (2004)
[7] See Hvid et al. (2004), only in danish

Table 7. Farm gate N-turnover on representative specialised Danish dairy farms in 1999 and 2002 after implementation of environmental regulations (VMP-II). Kg N ha^{-1} year^{-1}.

		Conventional				Organic			
	Year	1999[1)]		2002	(pilot farms)	1999[1)]		2002	(pilot farms)
	Number of farms	350		379	(25)	149		147	(13)
	Avr. LSU ha^{-1}	1.46		1.45	(1.54)	1.30		1.20	(1.14)
Input s	Fertilizer	95		66		0		0	
	Fixation	29		29		76		78	
	Manure etc., import	4		3		15		8	
	Supplement feed	91		96		50		53	
	Precipitation	16		16		16		16	
	Total input	**236**		**211**		**156**		**155**	
Outputs	Milk	-35		-37		-28		-26	
	Meat	-10		-9		-6		-5	
	Cash crops	-11		-8		-2		-2	
	Manure export	-3		0		0		0	
	Total output	**-53**		**-54**		**-36**		**-33**	
Farm gate N-balance		**184**	**(177)** [2)]	**157**	**(155)** [3)]	**121**	**(116)** [2)]	**122**	**(98)** [3)]
	Difference from conv. 2002					-37	(39)	-36	(57)
	Gaseous loss stable & storage	-22		-22		-18		-17	
Field N-balance		**161**		**135**		**102**		**105**	
	Amm. loss animal manure and crops	-19		-19		-13		-12	
	Denitrification, field	-17		-16		-14		-13	
	Soil-N change	**+31**		**+31**		**+34**		**+35**	
	Leaching estimated by difference[4)]	**-94**		**-69**		**-39**		**-45**	

[1)] Average dairy farms from tables 5 and 6

[2)] See table 6.

[3)] Lsmeans estimate in year 2003, see Nielsen and Kristensen (2005).

[4)] Leaching and soil-N changes= field balance – amm. loss – denitrification +/- soil-N changes. For example organic dairy in 1999: 102 –13 -14 -34= 39 kg N ha^{-1}.

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Appendix

In the Danish dairy sector, N-fixation in grass/clover swards constitutes a significant N-input. On pilot farms, clover content is evaluated visually and the fixation is calculated directly from visual clover content (Table A1).

Table A1. Total input of atmospherically derived nitrogen (totally fixed – kg N ha^{-1}) at varying clover content and different cropping year, Kristensen et al. (1995).

Visual clover content (soil cover) (dry matter clover content)	10-29 (13-16)	30-49 (17-29)	Above 49 Above 30
1st and 2nd year sward	78	156	248
3rd and older sward	47	84	128

Fixation in pure legume crops with measured yield is calculated after Høgh-Jensen et al. (2003). Mixed crops of peas and cereals are calculated with a combination of the two methods (Kristensen and Kristensen, 2002).

In order to calculate the fodder N import from economic figures, the yield of roughage must be known. The average roughage yield from 10 years of 15-30 pilot farm studies per year has been chosen. The yield is presented as Scandinavian Feed Units (SFU), where 1 SFU is equal to the feeding value of 1 kg barley grain (see Table A2). On conventional dairy farms permanent grass is set to 2,230 SFU/ha (= 2,768 kg DM/ha), and on organic dairy farms 2,000 SFU ha^{-1} (= 2,386 kg DM ha^{-1}).

The yield has been described in detail by Halberg & Kristensen (1997). The herd feed requirement is calculated in relation to milk and meat production measured. From milk production the yearly demand for fodder (Y) is calculated from Østergaard & Neimann-Sørensen (1989):

$$Y = 1000 * (-400+\sqrt{((400^2 – 4 * 16.7 * (1860 - X)))}) / (2*16,7)$$

Y = SFU demand per dairy cow per year
X = Kg milk production per dairy cow per year

The total demand for N in feed is calculated so that a total of 24,3% N efficiency is achieved in conventional dairy cows (Poulsen and Kristensen 1998) and 23.0% on organic dairy cows.. The N-efficiency of young stock is set to standard from Poulsen and Kristensen (1998). The need for N and energy import is achieved by a combination of the “know” produced home-grown feed and also the needed combination of grain and concentrate feed import. The N efficiency is equal to the average level of around 30 pilot farms in 1997-2001.

Table A2. *Net yields and crude protein content for field production on conventional and organic farms selected for modelling technical turnover on representative farms in 1999.*

System:	**Conventional**				**Organic**			
	SFU ha^{-1}	~Kg DM ha^{-1}	~GJ dig. energy ha^{-1}	% crude protein of DM	SFU ha^{-1}	~Kg DM ha^{-1}	~GJ dig. energy ha^{-1}	% crude protein of DM
Crops								
Grass/clover silage	6666	7400	91	16.8	5525	6133	76	16.8
Grass/clover grazed	6666	7200	95	22.0	5525	5967	78	22.0
Whole crop[1)]	4470	6035	54	10.4	3522	4754	42	10.4
Maize	8957	10456	117	8.7	6587	7706	86	8.7
Fodder beets	10800	10989	152	7.4	9248	9340	129	
Grain	measured			10.1	measured			10.1

[1)]Exclusive grass harvested during the autumn.

To calculate the fertilizers' import, a fertilization of permanent grass was set to 80 kg N/ha. All other crops have been given the maximum allowed level of mineral fertilizer including around 50% fertilization value of the nitrogen in animal manures. In order to achieve the national level of fertilizer use, 8% extra N fertilizer was given to all crops.

In Table A3, N-standards of the most important crops are shown, as applicable in 1999. After the establishing year the N-standards are not influenced by the age of the grassland. The N-standards are the maximum amounts of N from mineral fertilizer plus animal manure. N in cattle manure is expected to have an affectivity of 60% of artificial fertilizer, and therefore only 60% of total-N in cattle manure is included in the calculations. As mentioned earlier, one of the advantages of short-lasting grassland is the residual effect on the following crop. In the N-standards the residual effect of grass/clover is estimated at approximately 60 kg N ha^{-1} for the first year, when compared to the residual effects after a grain crop (Table A3).

Table A3. Standards for maximum N-application at a certain annual net yield (yield-standard) are shown for some crops on two soil types in 1999. In total there are 99 N-standards for different agricultural crops on three different soil types and for sandy soil there are standards for both irrigated and unirrigated.

	Sandy soil		Sandy loam soil	
	N-standard kg N ha^{-1}	Yield-standard t DM ha^{-1}	N-standard kg N ha^{-1}	Yield-standard t DM ha^{-1}
Grass crop				
Permanent pure grass	27-140[1)]	0-4	27-140[1)]	0-4
Established short lasting:				
Grass/clover, < 50 % clover	233	6.0	233	6.5
Establishing year after harvest of cover grain-crop:				
Grass/clover	54	1.0	53	1.0
Spring barley				
Cereal as previous crop	116	4.1[2)]	108	5.9[2)]
Grass/clover as pervious crop	85	4.1[2)]	78	5.9[2)]

[1)]Depending on yield level
[2)]Grain yield

In table A4 the percentage losses from main farm types is shown, The stall and storage ammonia and denitrification N-losses in mainly updated from Andersen et al (1999) and Poulsen and Kristensen (1998). The denitrification in field is from Vinther and Hansen (2004).

Table A4. Danish standard gaseous N-losses in 1999. [% of input].

		Mixed dairy Conv.	Mixed dairy Org.	Pig	Arable
Ammonia loss					
-from stall	% of excreta	4.6	4.1	15.3	10.8
-from storage	% of produced	4.7	4.3	4.6	4.5
-from spread manure	% of spread	8.4	8.4	8.9	8.8
-from grazing animals	% of excreta	7.0	7.0	7.0	7.0
-from applied artificial fertilizer	% of spread	3.0	-	3.0	3.0
-from crops	% of N-yield	2.9	1.4	5.2	5.2
Denitrification, total	% of field input	7.0	8.0	7.5	6.9
Denit. from solid manure storage	% of storage inputs	2.4	3.7	1.4	2.0
Denitrification, field	% of field input	5.9	6.5	6.7	6.7
-from N_2O	% of field input	1.7	1.8	1.8	1.6
-from N_2	% of field input	4.3	4.6	4.9	5.1