Dairy farm production strategy and nitrogen surplus

Niels Halberg & Carsten Hvelplund Jensen
Danish Institute of Animal Science

1. Introduction

Via public legislation minimum standards for the utilization of manure have been introduced as an obligatory part of fertilization planning. And many Danish livestock farmers have improved the utilization of manure during the last five to ten years. There is, however, still not consensus concerning the question of whether the results are sufficient to reduce the loss of nitrogen to ground water and the Danish marine environment to acceptable levels.

In an analysis of 30 dairy farms Halberg et al. (1995) showed a variation in N surplus between 88 and 387 kg/ha depending on stocking rate and management. At ca. 1.4 livestock units[1)] per ha there was a difference between 250 and 116 kg N/ha farm level surplus. It was concluded that differences between farms with comparable stocking rates were more dependent on differences in crop rotation and fertilization strategy than on animal feeding levels and production. There is, however, a need for a better understanding of the relations between different feeding and crop cultivation strategies both from a management and a regulations point of view.

We therefore find it interesting to study the possibilities for reducing dairy farm N-loss and how they can be exploited in commercial farming. We take the perspective of the farm and will show the need to understand the interdependencies in the production system and between the production system and -the different functions of- the management system. For this purpose we suggest a method called systemic modelling (Sørensen & Kristensen, 1992) where empirical findings from farms studies and experimental knowledge together form the basis for the development of computer models. This paper will

- present modelled results concerning the possibilities for a reduction in dairy farm N loss and on the basis of this and earlier empirical findings,

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1) 1 livestock unit (LU) is equal to 1 Dairy Cow of approx. 550 kg.

- discuss some important aspects of farm nitrogen balances (stocking rate, feeding strategy, fertilization strategy, management style),

- demonstrate the need for an integrated model that can handle interdependencies between crop and livestock production and

- discuss the importance of these recognitions when considering regulation of farm N losses.

2. Materials and methods

We have found it feasible to study the question of dairy farm N turnover and loss from a systems point of view, where the farm is seen as a cybernetic system (Sørensen & Kristensen, 1992; Rasmussen & Dalsgaard, 1994), consisting of a management system and a production system. The production system in our model consists of the herd and crops subsystems respectively and a manure storage part. The modelling of dairy farm N-turnover, we use, was developed by Kristensen & Kristensen (1992) and the interpretation further developed in Halberg et al. (1995). Some of the figures and ideas presented here originate from those papers where also more details on data and calculation methods can be found.

The new results presented here were calculated using the model SAMSPIL (Hansen & Kristensen, 1996), which is a decision support tool integrating dairy herd fodder planning and milk production with crop-rotation and manuring planning. The program is under development in a joint research project between the Danish Institute of Animal Science and the Danish Institute of Plant and Soil Science and is aimed at advisors and researchers interested in the interdependencies between crop and livestock production. It consists of several modules :

1. A tool for the planning of dairy herd feeding rations calculating the expected milk yield from the fodder rations proposed by the user.

2. From the former feeding plan ("last winter") and data concerning type of stable etc. the resulting manure production is calculated (amount, N-content and monthly distribution) after deduction of ammonia volatilization (NH_3-loss) calculated after Laursen (1994).

3. A tool for crop rotation and manuring planning. With this the necessary acreage with fodder crops - grass-clover, small grains for harvest or whole-crop silage, fodder beets etc. - is calculated and adjusted for the expected yields. The yields are predicted from nitrogen (N) response functions at different soil types presented in Rude (1991). The yield levels (i.e. the intercept value in the quadratic functions) have been adjusted for differences between organic and conventional yields according to Halberg & Kristensen (1996). SAMSPIL predicts the available N mineralized from N in soil organic matter and from supplied manure N. N-fixation is calculated according to Kristensen et al. (1995).

4. Farm level N-loss is calculated according to a simple input-output model presented in Halberg et al. (1995).

With SAMSPIL different production plans were simulated for a 75 cow dairy herd including 75 calfs/heifers and with an area in crop rotation varying from 100 ha to 59 ha irrigated sandy soil. For each stocking density a protein rich and protein poor diet were modelled (using the level of the protein balance in the rumen (PBV, see Hvelplund & Madsen, 1990)). Thereafter the necessary or suitable crop rotation and the proportion of area with each crop were established. For each combination of livestock density and PBV level three types of plans were made: A conventional system using imported concentrates were modelled with two different approaches to fertilization. As the third type a "low-external-input" system following the rules for organic farming was included as a critical case.

In all conventional plans fertilizer applications were determined for individual crops from estimates of their total demands and after deduction of the manure N supply. The total fertilizer input was limited according to the public rules demanding an average use of 55% of standard manure N content (for slurry based systems from 1997, Anonymous, 1995). Conventional yields were determined from the analysis by Halberg & Kristensen (1996) and nitrogen fixation was estimated to 100 kg/ha grass-clover as in Kristensen & Kristensen (1992). The conventional feeding plans were combined with two types of fertilization planning differing in the way manure N content was used.

1. One type was made using standard values for manure-N production following official standards and public rules (Anonymous, 1995).

2. The second type used an amount of N in manure calculated from the difference between fodder N intake, animal production and ammonia volatilization during storage via SAMSPIL.

3. The third type followed organic farming rules limiting the input of purchased conventional concentrates to 15% of the fodder units and prohibiting the use of chemically produced fertilizers. No imported manure was used in these plans, why they all have a large area with grass-clover with an asumed high N-fixation (171 kg N/ha).

Table 1 shows the different crop rotations for seven combinations of feeding and fertilization strategy and stocking rate. On the one hand feeding strategy affects choice and amount of foddercrops. On the other hand the total area and amount of nitrogen available for crop growth set limits to the choice and combination of feeding plans. Therefore the plans differ in the combination of crops according to stocking rate and desired protein levels in the feed rations.

TABLE 1. **Partition of area (hectares, ha) with different crops in nine combinations of stocking rate PBV level & fertilizer level (see text for explanation).**

ha	Conventional farming			Organic farming			
PBV-level	high + low			high		low	
LU/ha	1.0	1.4	1.7	1.0	1.4	1.0	1.4
Grass - clover	31.1	31.1	28.2	68.6	63.6	50.1	50.1
Whole-crop silage	25.4	25.4	25.4	0.0	0.0	21.8	17.2
Fodder-beets	5.2	5.2	5.2	0.0	0.0	4.1	4.1
Grain	38.3	9.7	0.0	31.4	7.8	24.1	0.1
Total	100.0	71.5	58.8	100.0	71.4	100.0	71.4

Table 2 shows the feeding plans and PBV levels at different stocking rates in the conventional and organic model farms.

TABLE 2. **Dairy cow winter feeding plans (1/11 - 30/4) with two levels of protein supply at modelled conventional and organic farms. FU per cow per day (1 FU equals the energy content in 1 kilo barley).**

	HK	LK	HØ	LØ
Grass - clover silage	0.0	0.0	8.6	5.4
Whole crop silage, barley	7.5	7.5	0.0	3.3
Fodderbeets	4.4	4.4	0.0	3.2
Barley	1.8	0.0	2.5	1.4
Grass pellets	0.0	0.0	2.2	0.0
C-11, concentrates	3.1	3.1	0.0	0.0
Rapeseed cake	0.0	0.0	1.7	1.6
Straw	0.1	0.1	0.1	0.1
Daily milk yield per cow	20	19	20	19
FU total per day	15.0	15.0	15.0	15.0
Urea, g/cow/day	150			
PBV, g/FU	27	3	37	-1
g/cow/day digestible crude protein	139	115	152	112

3. Results

3.1 Stocking rate

Table 3 shows the farm level N balance for the six combinations of protein level (high and low PBV) and fertilization strategy by stocking rate. The results show that with the same feeding strategy (i.e. low PBV), the N surplus on the modelled farm with 1.7 LU/ha was 32 and 65% higher than in the 1.4 and 1.0 LU per ha models respectively.

3.2 Feeding strategy

To show how different feeding strategies on the same farm affect N-surplus high and low PBV plans were compared. A lowering of PBV from the high level of 27 g/ FU per cow per day to 3 (Table 2) resulted in a 12 kg decrease in N-surplus per cow during a winter feeding period of 181 days (from 67 to 55 kg manure N per cow). This difference was also found on the farm level, if no correction for changes in manure N content was done. Following standard values for manure N production per cow the farm level N surplus decreased from

TABLE 3 **Farm level N turnover and surplus (kg N/ha) in six combinations of PBV and fertilizer levels by stocking rate (only conventional plans at 1.7 LU/ha) (kg N/ha).**

1.0 LU/ha	Conventional, public reg.		Conventional, best knowledge		Organic farming	
PBV-level	*high*	*low*	*high*	*low*	*high*	*low*
N (feed)	47	38	47	37	19	18
N (fertilizer+straw)	136	136	126	134	3	4
N (fixation+deposition)	52	52	52	52	138	107
N (milk+meat+grain)	-71	-71	-71	-71	-47	-41
N-surplus	164	155	154	152	113	87

1.4 LU/ha	Conventional, public reg.		Conventional, best knowledge		Organic farming	
PBV-level	*high*	*low*	*high*	*low*	*high*	*low*
N (feed)	65	53	65	53	46	26
N (fertilizer+straw)	131	131	117	127	8	10
N (fixation+deposition)	65	65	65	64	173	141
N (milk+meat+grain)	-56	-56	-56	-56	-31	-27
N-surplus	205	192	190	188	197	149

1.7 LU/ha	Conventional, public reg.		Conventional, best knowledge	
PBV-level	*high*	*low*	*high*	*low*
N-surplus	270	255	253	251

205 kg per ha to 192 kg per ha (13 kg N per ha) at 1.4 LU per ha (Table 4). If, however, attempts were made to calculate the real manure N content in both situations and the use of fertilizer was adjusted accordingly then the farm-level difference between high and low PBV levels was reduced to 2 kg N per ha or 1%.

In the organic system the high and low PBV plans differ especially in the level of grass-clover in the fodder rations. Therefore the relatively large difference in farm N-surplus (149 vs. 197 kg N per ha at 1.4 LU per ha) was primarily caused by a high increase in average N-fixation in the high PBV plan.

TABLE 4. **Differences in fodder protein levels and resulting N-surplus at cow and farm level[1)].**

	kg N per cow (181 days)			kg N per ha per year			
				Standard[2)]		Best knowledge	
				LU/ha			
	Fodder	Milk & meat	Surplus	1.0	1.4	1.0	1.4
High PBV	87	20	67	164	205	154	190
Low PBV	74	19	55	155	192	152	188
Decrease	13	1	12	9	13	2	2
%	15	5	18	5	6	1	1

Notes 1: Only winter feeding period showed at cow level while the farm level was calculated at an annual basis.

Notes 2: Standard = using standard values for manure N content in fertilizer plans. Best knowledge = using values for manure N production calculated from 365 days cow - intake and milkproduction.

3.2 Fertilization strategy

The results in table 3 demonstrate the effects of the three different approaches to manuring and fertilizing. At the lowest stocking rate and protein feeding strategy the N surplus differed between 87 and 155 kg N per ha (68 kg or 79% increase from no fertilizer to fertilization after public standards). The corresponding difference was 43 kg N per ha (28%) at 1.4 LU per ha and low PBV, while there were almost no difference (5%) between high PBV plans.

The differences between the conventional strategies were larger in the high PBV plans and increased with stocking rate. Thus, at low PBV and 1.0 LU per ha the aggregated effect of using best knowledge of manure N content in stead of standards were 3 kg N per ha lower N surplus while the same difference were 15 kg N per ha farm N surplus at 1.4 LU per ha and high PBV. In other words: Using calculated specific values for manure N content saved on 2-17 kg N per ha in fertilizer and therefore reduced N surplus accordingly.

4. Discussion

How important are different measures for reducing N-losses from dairy farming?

Stocking rate

A correlation between the livestock density (LU per ha) and surplus of N (increasing N-surplus with increasing stocking rate) have been found in several studies; see Halberg et al. (1995). The main reason for this is probably that a large percentage of manure N is not easily utilized for plant growth because it is part of the organic matter in the manure (organic N). Mineralization of the organic N occur over a longer period than plant growth, why some of it is lost out of the soil during periods with excess precipitation. The larger the amounts of manure supplied per ha, the larger this loss will be under given circumstances.

Some more interesting questions thus are:
How large a variation can there be at a certain stocking rate?
How small a loss is it possible to get at different stocking rates by adjusting feeding and crop cultivation strategies ?

Feeding strategy

The results show that there is a potential for reducing N in manure by low PBV feeding strategies given current planning rules. The effect on cow level was a 18% lower N surplus in conventional feeding plans (table 4) and the largest effect on farm level N surplus was a 25% reduction in the organic system (table 3). In our examples the differences in PBV levels between systems with equal stocking rates were obtained by varying the level of N in supplementary feeds (urea added to whole crop silage at the fodder table). If the reduction of PBV had been achieved by changing a grass-clover based system to the grain based crop rotation used here the effect would have been ca. 10 kg N/ha higher (results not shown).

Kristensen (1995) predicts that it will be possible to reduce N in excreta from dairy cows 10% compared with current levels by reducing PBV levels to near zero. However, it should be noted that reductions in animal protein feeding almost only affect the amount of urea-N from the cows, which means that the organic N content in the manure is not affected. Therefore the potential for reducing farm N loss in this way might be limited and in any case depends on the way fertilizer use is planned. These interdependencies between feeding and fertilization strategies are further discussed below.

Fertilization planning

The N surplus was lower in the organic system compared with the conventional systems at all levels of stocking rate and PBV. The difference was smallest under the high PBV plan reflecting the higher area with grass-clover crops. The N fixation in organic grass-clover was expected to be 71% higher than in conventional due to a higher clover content. This figure is probably one of the most insecure in the model and is not treated dynamically, i.e. it was assumed constant regardless of manure N content.

However, in a comparison of 14 organic and 16 conventional dairy farms Halberg et al. (1995) also found farm N surplus to be significantly lower on organic farms after corrections were made for stocking rate. The same model as used here were used for calculation of N fixation and the differences between systems were still significant even under the unrealistic assumptions of a 50% higher N fixation than modelled. There were no systematic differences in cow N turnover (N in feed ration and in milk and meat production) on organic and conventional farms. Therefore, it was concluded that the difference in farm level N surplus was caused by the different crop growth strategies, the main reason being that organic crops were able to utilize more of the N mineralized from organic N. The consequences of these different approaches might be explained by studying the proces of fertilization planning normally used by livestock farmers as explained in detail in Halberg et al. (1995) where also references can be found:

An economically optimum level of (total) N supply for each crop is calculated on the basis of local yield expectations, N response values from experiments and prices of the crop and mineral fertilizer. Three factors are subtracted from this optimum economic supply: 1. The expected or measured amount of mineral N in the soil in early spring (N_{min}). 2. The expected amount of mineralized N released from soil organic matter during the growth season - including mineralized N from manure applied in previous years (N_{soil}). 3. The amount of manure applied to the crop multiplied by a utilization factor (first year effect). The utilization factor expresses the percentage of the total N in manure that the crop is expected to utilize during the (first) growing season. This percentage equals the amount of fertilizer N that 100 kg of total N from a given type of manure can replace under given conditions (time and method of application), which again have been established by experiments. Thus, the calculation for each crop is as follows:

Economically optimum fertilizer application =
Economically optimum N supply - N_{min} - N_{soil} - (N_{manure} * utilization factor)

In a given situation several factors add great uncertainty to this calculation:

1. The possibility of lower (or higher) yield than expected from drought, pests or weeds causing decreased crop N uptake.

2. For some crops - especially grass and grass-clover for grazing - the knowledge behind the assumed optimal N supply is insufficient.

3. Variations in manure N content and the amount of manure available. As it was indicated above the amount and concentration of N in slurry per LU is influenced by animal feeding levels, the type of N in the feed and animal utilization for production of milk and meat production, N loss in stable and during storage and the amount of water (rain + spill over from animals drinking water) in the slurry storage tank.

4. Variations in the utilization factor (first year effect) of the applied manure from variations in ammonia loss during application.

5. Different N mineralisation during the growth season than expected because of climatic conditions or lack of knowledge concerning the impacts from previous crops.

Thus, there is a lot of room for judgement even if the farmer assumes knowledge of manure N content instead of using standard values. Since nitrogen fertilizer is relatively inexpensive some farmers tend to secure crops against lack of N when attempting to "optimize" N input this way. Halberg et al. (1995) showed how none of the conventional crops in this analysis removed more nitrogen than was supplied the same growing season. Therefore the net-mineralization was never utilized by the crops; not even in fodderbeets with a long growing season. Contrary to this, most organic farms had at least one crop in the rotation -usually fodderbeets or whole crop silage- which harvested more N than was supplied by manure or nitrogen fixation. This was seen as the main explanation of the lower farm N surplus on the organic farms.

Interdependencies between fertilization and feeding strategy.
It has been suggested that N loss from livestock farms could be reduced by optimization of animal protein feeding because it reduces N in excreta. From the above explanations three points become relevant for judging such a proposal:

1. Only if *unchanged standard values* for manure N are used for fertilization planning will the conventional farm's N loss be reduced proportionately to the reduction in N surplus

at the animal and herd levels. This is because the fertilizer applications in this situation will remain the same (all other things being equal). But if the crop yields decrease because of the lower total N supply, then the effect on the farm level might be partly counterbalanced by an increased N input from purchased fodder or concentrates.

2. If however, the farmer takes the *reduced manure N content* into account in fertilization planning (best knowledge plans) and therefore increase fertilizer purchaces the effect of lower manure N content will be small. Since the amount of organic N in manure is almost unaffected by lowering PBV, the problems of utilizing this part remains the same. Reductions in farm N surplus will therefore be limited to the reductions in ammonia volatilization from stables and manure storages because of the lower urea production.

3. In a system where N input is limited -like the organic- the effect of a decrease in PBV would probably be larger as suggested by table 3 (ca. 23% regardless of stocking rate).

Farmers decision making

The organic and conventional management systems differ in their way of planning crop rotation, crop manuring and fertilization. The conventional farmer most often use the single crop optimization methods explained above. (Today though, new public rules set minimum standards for the calculation of manure N utilization factors and maximum standards for manure N content and crop N needs in relation to ecpected yields). The organic dairy farmer however has a more tight restriction on N input from as well manure as fertilizers, limiting the total amount of manure applied to the equivalent of 1.4 LU/ha, according to specific rules for members of LØJ, the largest organization of Danish organic farmers. Therefore any attempt at "securing the N needs" of a particular crop or field will be at the cost of another field. So he will naturally have to rely more on soil N turnover and crop rotation to optimize plant N supply, which was one of the purposes with this self imposed set of rules that organic farmers follow.

It seems then, that an overall - severe - limit on N input to the organic cropping system forces the farmers to optimize the N efficiency in the crop rotation and in single crops. Because of the low N supply most of these crops are capable of utilizing for instance unexpected high mineralization during the growing season. This effect might possibly also be achieved just by reducing fertilizer levels. How severe a reduction compared with the "economic optimum" N levels is needed depends on the acceptable limits of N loss. But to significantly reduce overall N surplus from livestock farms (i.e. more than in the above examples with low PBV and "best knowledge") a better utilization of organic N in manure would probably be needed than is presently the case using single crop optimization methods.

The results presented show the important interdependencies between on the one side the herd and the crop production and on the other side the production system and the management system. Therefore any analysis of policies aimed at reducing N losses should

1. account for all consequences and interdependencies through the whole system and

2. include an understanding of different farmers goals and their importance for fertilization decision making.

The need to understand different farmers decision behaviour has been stressed in discussions of the development of management tools and farm-environment relations (Jacobsen et al. 1994). There might be large differences in the way farmers percieve the question of the right fertilizer levels. Roep & Roex (1992) linked variation in farm N surplus to differences in farming styles (i.e. the overall development path followed by a farm manager). And Noe (1996) found similar patterns in the levels of fertilizer input to grass-clover crops among danish dairy farmers with no correlation between N input and yields.

Regulation of farm N loss

It should be noted, that the organic system, while today being an established commercial dairy system, is used in this paper only as a critical case. The N surplus was lower in the organic compared with the conventional system at almost all combinations of PBV and stocking rate indicating the potential for reducing N loss with this type of system. However, intermediate systems might very well reduce N losses to acceptable levels and at the same time benefit from the greater freedom for management in conventional systems. But recalling the discussion of the difference in management systems one has to keep in mind the questions of how to limit the fertilizer input and after which criteria. Single crop optimization and standard values for animal manure content seems not to be a convincing method.

Likewise, just reducing fertilizer input might not be a goal in itself because, commercial fertilizer N might to a certain extent be substituted with N fixation: Grass-clover based dairy systems can -as demonstrated above- have substancial N input from the fixation of atmospheric N. If the fields are part of a crop rotation a large part of this nitrogen might be lost when the crop is ploughed. The crop rotation should therefore seek to maximize use of N mineralized from the grass-clover residues. This again demonstrates the need to consider the overall N-balance of the farm to avoid sub-optimization and problems of "rule-thinking".

A relevant way to regulate N loss might be to stimulate (or coerce) farmers to include the overall N surplus in their management decision making. How this could be accomplished using levies or taxes have been discussed by Gaarn Hansen (1991), Rude (1991) and Doluschitz et al. (1992). We have tried to demonstrate, that it might be interesting to ask what the possibilities are for producing (for instance) milk with low N-loss. This should then be combined with a discussion of acceptabel levels of loss from different points of view. In this way a more constructive debate of the possibilities for combining commercial livestock production with environmental concern might be facilitated. Such a debate would possibly need a more local or regional fundament so that differentiated knowledge might be used in the development of compromises (Deffontaines et al. 1993; Röhling, 1994).

The need for integrated models

From the discussion above, we find it is an important task to develop models of livestock farm N turnover that account for the interdependencies in the system and the total N surplus. The present modelling of the different types of N losses in SAMSPIL is not totally satisfactory. The standard values for NH_3-loss will be exchanged with FARMVOL (Hutchings et al. 1996), a simulation model of ammonia volatilization. It is expected that a more sophisticated model of soil-N turnover (Olesen, pers. comm.) can be linked to SAMSPIL in order to predict N mineralization from previous crops and the nitrate leaching. A crucial point is, however, to get a model that can explain the totality of the farm's N turnover and surplus. Therefore, the predictions of the partial losses must be coherent, ie. in accordance with the actual overall farm N balance after adjustments for expected changes in soil-N fractions.

Some of the different plans presented would only be attainable at a particular farm after a period of adjustments, i.e. change of crop rotation, feeding system or investments in more land. Therefore, for a farmer such considerations would belong to the strategic planning process. However, it would be interesting also to consider even more drastic changes in a farm's production facilities in relation to N-loss. For instance in the housing of animals or attempts to catch the NH_3 volatilization from slurrytanks. Such considerations have not been dealt with here. In a research project called "The development of an ethical accounts system" 1993-97 (Halberg et al. 1994; Klint Jensen & Sørensen, 1996) a decision support tool is being developed to facilitate farmer' considerations of resource use, environmental impact and animal welfare in their strategic planning.

5. Conclusion

Stocking rate, protein level in feed rations, crop rotations and manuring and fertilization strategies all influence dairy farm N surplus. At a certain stocking rate large variation is possible. The most influencial strategies to reduce farm N surplus in these examples were to reduce stocking rate and fertilizer input considerably thereby forcing the crops to utilize a larger amount of organic N in manure and soil. The effect of different PBV levels depend on fertilization strategy and will probably be partly counterbalanced by increased fertilizer use if traditional optimization methods are used.

Thus, large possibilities excist for reducing dairy farm N surplus if this is necessary for environmental protection. However, the most efficient ways, ie. lowering stocking rate or severely limiting N input from fertilizers, might be costly. Organic farms might be good fix points for such considerations, since the technical and economic results from such commercial low-external-input systems are available today.

The different aspects of farm N loss in relation to management demonstrate the complex relations within the farm. Public regulation aimed at subsystems or single input factors might not be very efficient because of interdependencies and possibilitities for substitution and "rule-thinking".

Because of the many factors contributing to farm N-loss and interdependencies between subsystems it is not easy to model and predict the effects of policies aimed at regulating the use of single input factors or parts of the farming system. At least a thorough understanding of different farmers goals and their management methods is needed. Moreover, there's a need for farm models that take all interdependencies into account and predict N losses from different systems while explaining the N turnover in a coherent way.

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