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Nitrogen management on experimental dairy farm 'De Marke'; farming system, objectives and results

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Abstract

In the sandy regions of the Netherlands, high nutrient surpluses from dairy farming harm the environment. Government policy aims at reducing nutrient losses to acceptable levels. To explore possibilities and to generate sufficient and accurate information for dairy farmers to reduce surpluses, research was carried out at the experimental dairy farm 'De Marke'. The objective of 'De Marke' is to design and operate a suitable farming system that meets strict environmental standards, taking into account societal objectives with respect to animal welfare, nature and landscape, and economic viability. A dairy farm is characterized as a system with soil, crop, herd and manure as components. Results of animal nutrition, crop yields and nitrogen (N) flows for the period 1993–1998 indicated that intensive farms could attain a N surplus of 158 kg ha^{-1}. So compared with a 'current average' farm in the middle of the 1990s with the same milk production level (N surplus of 408 kg ha^{-1}), a reduction of 62% in N surplus was realized. At 'De Marke', especially the input of purchased feed and chemical fertilizer was much lower. The most important characteristic of the farming system 'De Marke' was the realization of very high N utilization efficiencies in animal nutrition and crop production, allowing a similar milk production but at a much lower input level. With an ammonia volatilization level of 20 kg N ha^{-1} – which is much lower than the 64 kg ha^{-1} on the 'current average' farm – the target of 30 kg N ha^{-1} was attained. Total crop yields (pasture grass, grass silage and silage maize) at 'De Marke' were lower than expected. With a realized N surplus of 156 kg N ha^{-1} the target of 128 kg N ha^{-1} (including deposition and symbiotic fixation) was not yet attained.

Keywords: farming systems, Netherlands, systems research, environmental policy, prototyping, nutrient management.

Introduction

General

On the average dairy farm on sandy soils in the Netherlands, the input of nutrients from fertilizers and concentrates is much higher than the output in the form of milk and meat. The difference – the surplus – eventually affects the environment. Runoff and leaching of phosphate and nitrate pollute surface- and groundwater. Atmospheric deposition of ammonia leads to acidification and contributes to eutrophication. This leads to negative impacts on ecosystems, and cultural-historical heritage may be damaged. Government policy aims at restricting the losses of nutrients from dairy farming systems to the environment to acceptable levels based on explicitly defined objectives. The dairy farmer will try to minimize the costs associated with complying with government policies. To realize this, the farmer needs timely, sufficient and accurate information, and agricultural research should contribute to the generation and transfer of this type of information to the farmer. The project 'De Marke' contributes to that objective.

Objectives of 'De Marke'

Dairy farming is characterized by the combination of plant and animal production within one farming system. Via the exchange of feed and manure, minerals (nutrient elements) cycle through the system, resulting in unavoidable losses. In order to design a suitable farming system for 'De Marke', first the input-output relations were quantified. For the animal component of the system this included the relation between milk production and feed requirements (both quantity and quality), for the plant component the relation between crop production on the one hand and nutrient (fertilizer) and water requirements on the other. These quantitative relations served as the basis for a milk production system that in theory would meet strict environmental standards, taking into account societal objectives with respect to animal welfare, nature and landscape, and economic viability. Export of animal manure from the farm or raising young stock for replacement outside the farm was not allowed, as that would be associated with externalities. To design a system that would be recognizable for the 'common' dairy farmer, a milk production level of about 12,000 kg ha^{-1} was aimed at, which was the average for the sandy regions at the end of the 1980s (Aarts *et al.*, 1992; Biewinga *et al.*, 1992).

The environmental targets set for 'De Marke' with respect to nutrients (Table 1) are much stricter than the loss norms (maximum surpluses) formulated by the government in its manure legislation. These norms are a compromise between objectives with respect to environmental quality and the expected negative impact on agricultural production (Dekker & Van Leeuwen, 1998). On sandy soils susceptible to nitrate leaching, in the final situation the permitted N surplus for the 'current average' farm is 190 kg ha^{-1}. This surplus includes atmospheric deposition, the contribution from fixation by leguminous species, and the 'animal correction' (a correction for ammonia volatilization on the permitted surplus for arable land and grassland). The permitted phosphorus (P) surplus is 9 kg ha^{-1}. In designing 'De Marke', environmental quality was the only criterion. The targets, together with the deviations from the 'current average' situation in the middle of the 1980s, are presented in Table 1.

At that time the intensification of dairy farming effectively came to a standstill as a result of the introduction of the quota system in the European Union and because of the environmental legislation by the Dutch government. That moment can therefore

Table 1. Norms for the nutrient losses at the experimental farm 'De Marke', and the reduction in comparison with the 'current average' situation in the (reference) period 1983–1986 (Aarts *et al.*, 1992; Biewinga *et al.*, 1992).

Objective	Maximum value 'De Marke'	% reduction compared with the 'current average' in the middle of the 1980s
Nitrogen (N)		
Ammonia volatilization	30 kg ha^{-1}, from animal manure	70
Nitrate leaching	50 mg nitrate l^{-1}, in upper groundwater	75
Gaseous nitrous oxides	3 kg ha^{-1}	66
Surplus on farm balance	128 kg ha^{-1}, including deposition and symbiotic fixation	74
Phosphorus (P)		
Runoff/leaching	0.15 mg P l^{-1}, in upper groundwater	?
Surplus on farm balance	0.45 kg P ha^{-1}, including deposition	99

be considered as a 'turning point' in environmental load, and serves as the reference point for judging the improvements in environmental achievements of the dairy farming sector. Table 1 clearly illustrates that the targets for 'De Marke' only represent a fraction of the losses in the reference period. Further environmental objectives – not explicitly included in Table 1 – refer to the use of biocides, the accumulation of heavy metals, the emission of greenhouse gases, the use of water and energy, and the development of nature values. For these objectives only desired goals were formulated, but no explicit minimum or maximum values had to be realized (Aarts *et al.*, 2000).

This paper describes: (i) the farming system that has been in operation as dairy farm 'De Marke', aiming at reducing surpluses of average intensive farms by improved nutrient management, and (ii) the results of the nitrogen (N) management strategy, by presenting crop yields, animal nutrition and N flows.

Material and methods

The farming system

From the farming systems that theoretically would lead to realizing the objectives (prognosis), the most interesting one from a research point of view was implemented in 1992 on a farm that was especially acquired for that purpose. The farm has been further developed since as farming system 'De Marke' (Table 2). As replication was not realistic – not from a financial nor from a human resource point of view – the system is unique.

Land use

The experimental farm 'De Marke' comprises about 55 ha of land, which at the be-

Table 2. Characteristics of crops, animals and farm plan of experimental farm 'De Marke'.

	'93/'94	'94/'95	'95/'96	'96/'97	'97/'98	'98/'99	Average '93–'98
Milking cows	82.0	81.2	79.4	76.6	75.6	79.8	79.1
Young stock > 1 year	29.9	28.8	24.4	27.3	29.3	26.4	27.7
Young stock < 1 year	35.9	29.1	30.0	31.0	26.9	31.2	30.7
Young stock per 10 milking cows	8.0	7.1	6.9	7.6	7.4	7.2	7.3
Milking cows ha^{-1}	1.5	1.4	1.4	1.4	1.4	1.5	1.4
AU[1] ha^{-1}	1.9	1.8	1.7	1.7	1.7	1.8	1.8
Kg milk per ha	11,806	11,623	11,409	11,919	11,787	12,516	11,843
Kg milk per cow	8,005	8,102	8,119	8,791	8,622	8,516	8,359
Fat content (%)	4.39	4.37	4.50	4.31	4.14	4.17	4.31
Protein content (%)	3.49	3.50	3.50	3.47	3.42	3.42	3.47
Grass (ha)	30.6	35.0	34.2	29.2	26.5	31.5	31.2
Silage maize (ha)	13.1	10.1	13.7	20.2	20.1	14.1	15.2
GMES[2] (ha)	5.8	7.1	4.6	7.1	8.7	8.7	7.0
Fodder beet (ha)	6.1	4.4	4.0	–	–	–	2.4
Farm area (ha)	55.6	56.6	56.5	56.5	55.3	54.3	55.8

[1] Animal Unit: 1 milking cow = 1 AU; 1 young stock > 1 year = 0.439 AU; 1 young stock < 1 year = 0.22 AU.
[2] Ground Maize Ear Silage.

ginning of the 20th century was reclaimed from wasteland covered with heather. A 30-cm top layer with an organic matter content of about 5% overlays almost organic-matter free sand, impenetrable for roots (Dekkers, 1992). The groundwater level generally is several metres below the surface, beyond the reach of roots and hardly contributing to crop moisture supply by capillary rise. As a result the soils of 'De Marke' belong to the most drought-sensitive sandy soils of the Netherlands (Table 3), with half of the area having a moisture storage capacity below 50 mm. These drought-sensitive sandy soils are susceptible to nitrate leaching, which already starts following relatively low levels of precipitation. Moreover, denitrification is relatively unimportant. On these soils, nitrate and other N objectives are difficult to realize.

Table 3. The sandy soils at 'De Marke' compared with those of the Netherlands (Source: Dekkers, 1992).

Moisture storage capacity (mm)	Leaching susceptibility	Proportion at 'De Marke' (%)	Proportion sandy soils the Netherlands (%)
> 200	very low	5	20
150-200	low	6	26
100-150	medium	11	28
50-100	fairly high	28	8
< 50	very high	50	18

To grow all roughage and part of the concentrates necessary for a milk production level of 12,000 kg ha^{-1}, irrigation is indispensable.

The 55 ha of land comprise three parcel types: 11 ha of permanent grassland located close to the farm buildings, and two parcels of rotational grassland. On 30 ha of this – the home parcel – three years of grassland alternate with three years of maize. On 14 ha – the field parcel – three years of grassland alternate with five years of maize. The most important differences between the home parcel and the field parcel are the possibilities for irrigation and their accessibility. The home parcel can be irrigated, the field parcel, which is farthest away from the farm buildings, cannot. Consequently, grazing intensity is higher on the permanent pasture and the home parcel than on the field parcel. An advantage of the rotation is that organic matter content is maintained at a higher level than under continuous maize. This has a positive influence on moisture holding capacity and rooting characteristics. Moreover, in the rotation, nutrients not utilized by the present crop, and thus left in the soil, can be utilized by the subsequent crop. In addition, weed problems are smaller. The yield of maize generally is substantially higher in rotation than under continuous cropping (Scholte, 1987).

A little over half of the area is used as grassland. On the remainder maize is grown. Compared with most commercial farms on sandy soils in the Netherlands the proportion of maize is high. Maize produces higher forage yields than grass. Moreover, on the drought-sensitive soils of ' De Marke' less irrigation is required. In other words, a larger proportion of maize would restrict the use of groundwater and reduces the purchase of feed. Furthermore, a high proportion of (energy-rich and low-protein) maize in the ration reduces N excretion by the animals.

Fertilization

Fertilization is based on a number of principles, the most important one being that all animal manure should be used on the farm in a responsible way. This allows maximum utilization of its nutrients by the crops, so that the use of chemical fertilizer is minimized. In addition, fertilizer management aims at minimizing nitrate leaching, and realization of the nitrate objective. For P the principle of equilibrium manure application is used, i.e., the amount of nutrients applied with the manure should not exceed the amount of nutrients exported with the crops.

The basic levels of N fertilizer application are 250 kg ha^{-1} for grass and 100 kg ha^{-1} for maize. Fertilizer levels are determined per plot, taking into account the crop, the moisture-supplying capacity of the soil, the P status of the soil, and the N supply from ploughed-in sod and green manure. The nutrient requirements are covered as much as possible from animal manure and symbiotic N fixation. On grassland, fertilizer application starts on 1 March, and on maize land shortly before sowing (early May). About 80% of all slurry is applied on grassland.

For maize the amount of slurry applied is determined by the N requirement, for grassland by the P requirement. The consequence would be that on maize land P fertilizer would have to be applied, and on grassland N fertilizer. However, this would be undesirable for the nutrient balance at farm level. Therefore, P fertilizer application strategy takes into account the rotation. A grass ley receives more P in the form of slurry than is taken up, whereas maize receives less. In this way the maize can take up P left in the soil by the grass ley. So on the grass ley about 73 m^3 of slurry per ha is applied, which is 23 m^3 more than on the permanent grassland. Slurry is applied in three doses using an injector. Application is discontinued after mid-August.

Table 4 clearly shows that the slurry produced on the farm serves as the main nutrient source. As a result, 75% less N fertilizer is used on 'De Marke' than on the 'current average' farm in the middle of the 1980s.

As the proportion of clover in the sward was lower than expected, so was N fixation. The mixture of grass and clover was well established in autumn after sowing, but clover generally strongly suffered from winter damage. Sowing the mixture in spring solved this problem. A remaining problem is the heterogeneous distribution of the clover, especially in the permanent grassland.

Catch crop

The nutrient uptake of maize almost ceases after the beginning of August. At that moment the soil still contains a substantial amount of mineral N, which increases through mineralization and cannot be taken up by the crop. To solve this problem, a catch crop of Italian ryegrass is sown between the maize rows, about six weeks after sowing the maize. Following the maize harvest, the ryegrass continues growing and takes up the residual N. Such a catch crop is very effective and is easy to include in farm management. The grass does not compete with the maize, provided a proper sowing date is selected. Part of the catch crop is utilized in autumn through grazing by the young stock.

Herd

To restrict nutrient losses at farm level, efficient nutrient utilization by the dairy herd is essential. To attain this objective, the herd should meet the following requirements (Biewinga *et al.*, 1992):

1. Genetic potential for high milk production per animal (about 9000 kg per lactation).

Table 4. Manure and fertilizer application per hectare (1993–1999).

Land use	Slurry				Chemical fertilizer	
	m^3	kg N-total	kg N-available	kg P_2O_5	kg N	kg P_2O_5
Permanent grassland	50	147	89	54	133	1
Grass ley	73	223	133	82	123	2
Maize	25	82	54	27	0	0
Average	49	150	92	54	74	1

2. Favourable characteristics for protein production, in combination with a low fat/protein ratio.
3. If possible, selection for persistency, fertility, life span and efficiency of feed conversion.

The herd is housed in a low-emission cubicle stable with natural ventilation. Herd size, with 80 milking cows and 58 young stock, is smaller than on commercial farms with a comparable milk production level. At 'De Marke', annual milk production per animal is about 1000 kg higher. Also feed requirements are lower, with the result that in addition to all the roughage, part of the required concentrates (substitutes) can be grown at 'De Marke'. Animal density equals 1.8 AU* ha^{-1}, including 7.3 young stock per 10 milking cows. Average annual milk production per cow (1993–1998) was 8359 kg, with higher values during the later years. Following the withdrawal of fodder beet from the rotation (from 1996/1997 onwards), fat content of the milk was well below the reference value of 4.33%.

Animal nutrition

In the summer period, until the season of 1999, the so-called siesta grazing system was followed for the milking cows, i.e., the animals graze for 4–5 hours in the morning and in the evening after milking. Each of these grazing periods was followed by a period indoors where a ration of silage maize, ground maize ear silage (GMES) and concentrates was supplied. In this way, the protein-rich grass is supplemented with low-protein components indoors. By shortening the periods of alternate supply of protein-rich and low-protein feed, the feed norms can be attained more easily, resulting in a higher N utilization efficiency. Additional advantages are lower grazing losses and restricted excretion of faeces and urine in the pasture, of which its strongly heterogeneous distribution increases the risk of leaching losses. Milking cows are stabled on 1 October, which is one month earlier than on commercial farms.

In the winter period, the ration consists of grass silage, maize silage and GMES. Half of the required concentrates is grown on the farm; the remainder generally is purchased in the form of mixed concentrates. GMES has proven its value as a concentrate substitute. A disadvantage of the common method of harvesting GMES is that the maize stover remains on the land. At 'De Marke', silage maize is harvested with a special machine that collects GMES and maize stover at the same time but separately. Maize stover contains little energy, protein and potassium, but high levels of (partly digestible) cell walls, making it an excellent component of the ration for dry cows and pregnant heifers.

* Animal Unit: 1 milking cow = 1 AU; 1 young stock > 1 year = 0.439 AU; 1 young stock < 1 year = 0.22 AU.

Results

Crop yields

In the design of 'De Marke' the main criteria for crop selection were N losses during cultivation, production with a limited moisture supply and the importance of the product in the ration (Biewinga *et al.*, 1992) This led to the choice of grass, maize and fodder beet. Comparison of the yields that were realized in the period 1992–1999, with the expected yields (Table 5) shows that the realized yields of silage maize were below expectation. Year-to-year variation was very high, and actual yields were mainly determined by soil moisture status during grain set. This is the reason why low grass yields resulting from moisture deficits can coincide with reasonable maize yields.

In part of the maize crop, cobs (GMES) and stover (stalks and leaves) were harvested separate from each other. The yield of GMES was higher than expected, and the yield of stover lower. In recent years the performance of the machine used for this separate way of harvesting was improved, which has resulted in higher stover yields. Consequently, more and higher-quality stover was harvested.

In the period 1992–1995, fodder beet was grown, with higher yields than expected. In 1994 and 1995, part of the fodder beet was ensiled together with maize, which required earlier harvesting, with associated lower yields. Yields of beet leaves were lower than expected.

In the prognosis, an overall average yield of almost 10,500 kg ha^{-1} of dry matter was calculated, whereas almost 10,000 kg were realized. In the years with favourable moisture supply (1993, 1997 and 1999), the average yield exceeded 10,000 kg ha^{-1}. On the other hand, spring of 1998 was extremely wet, which resulted in high mineral N losses, especially in maize, and consequently in low yields.

Table 5. Net crop yields (excluding grazing- and harvest losses) at 'De Marke' in the period 1992-1999, and the prognoses when the farm was started (kg dry matter ha^{-1}).

	Prog-nosis	1992	1993	1994	1995	1996	1997	1998	1999	Avg. '92-'99
Grass	9285	8886	9568	9185	9249	8035	10125	8865	9138	9125
grazing grass	4065	3744	4165	3574	3391	3292	4074	3435	3135	3588
silage grass	5220	5142	5403	5611	5858	4742	6051	5430	6003	5537
Silage maize	11167	8945	12068	9978	8460	11221	11248	9694	12723	10571
GMES[1]	7079	–	8328	6825	7246	7640	7311	6009	8236	7267
Maize stover	4248	–	1773	3144	2608	2680	3343	3573	4941	3162
Fodder beet	11633	13858	15798	9222	9173	–	–	–	–	12422
Beet leaves	2500	1649	2033	1743	1734	–	–	–	–	1830
Farm	10441	9496	11111	9567	9113	9459	10645	9217	10563	9892

[1] Ground Maize Ear Silage.

Animal nutrition

The summary of animal nutrition data in Table 6 for the period 1993–1997 (Habekotté *et al.*, 1999) shows that total feed use exceeded the prognosis by almost 9%. The milking herd ingested 6% more dry matter than expected, the young stock 23% more. The main explanation for the higher intake by the young stock is that in the design phase 46 head of young stock were taken into account, while in reality this was 58. As fodder beet was withdrawn from the ration in 1996, average intake of this feed was lower than expected. The lower-than-predicted intake of fresh grass was partly compensated for by a higher intake from late-season grass silage. The latter was the result of the early stabling of the milking cows. Utilization of by-products of concentrate substitutes, such as maize stover and beet leaves, and the grazing of the catch crop Italian ryegrass following maize, are important characteristics of nutrition management at 'De Marke'. Grazing by the young stock of the residual grass left by the milking cows, is also a form of utilization of 'waste products'. More concentrates were purchased than expected. The group-housing of the animals can partly account for this: it makes feeding individual animals according to the norms for both energy and protein, all but possible.

Nitrogen flows

First, the most important N flows for the farm as a whole are discussed, followed by the flows per component.

Table 6. Annual feed intake of the herd at 'De Marke' (tons of dry matter).

	Whole herd		Milking cows		Young stock	
	Prognosis	'93-'97	Prognosis	'93-'97	Prognosis	'93-'97
Grass silage	134	150	110	132	24	18
Fresh grass	146	111	108	66	38	44
Silage maize (including fodder beet)[1]	148	171	131	158	17	13
Residual roughage[2]	0	16	0	8	0	7
Other[3]	27	48	17	26	10	23
Total roughage	455	496	366	390	89	105
Fodder beets	65	22	62	21	3	1
GMES[4]	23	47	23	47	0	0
Concentrates	76	103	74	94	2	9
Premix	PM	4	PM	3	PM	0
Total concentrates	164	176	159	165	5	10
Total	619	672	525	555	94	115

[1] Sometimes part of the fodder beet was ensiled in combination with silage maize.
[2] Residual roughage left by the milking cows is fodder for young stock and dry cows.
[3] Other comprises maize stover, beet leaves and late season grass silage.
[4] Ground Maize Ear Silage.

Farm level

The total N cycle comprises the components herd, manure, soil and crop (roughage and pasture grass). These components can be considered the links in the N cycle. The N balance of each of the links shows the links' (in)efficiency of N utilization, which allows identification of the weakest link. In Figures 1 and 2 the N cycles are presented for 'De Marke' and for a 'current average' farm on sandy soil in the middle of the 1999s with a milk quotum equal to that of 'De Marke'. This 'current average' farm is a 'theoretical construct', designed by combining various data sources (Aarts *et al.*, 1999). The component 'roughage' comprises a correction for conservation and grazing losses.

The N surplus (Table 7) of the farm can be partitioned into ammonia emission, denitrification, accumulation in soil organic matter, runoff and leaching. The absence of surface water makes that runoff does not play a role. Average annual N surplus over the period 1993–1998 was 158 kg ha^{-1}, while the target for the farm was set at 128 kg ha^{-1} (Biewinga *et al.*, 1992). The excess surplus was the result of high inputs in roughage and concentrates and of the reduction in the stocks of slurry or feed.

Input in chemical fertilizer was low in some years, but not low enough to compensate for the high input in feed. Input via N fixation was substantially below expectation. On the field parcel no clover had been sown in the grass because of disappointing results of sowing in autumn. Most of the clover had disappeared after the first winter. In the last years, clover was sown in spring, and because of the mild winters its proportion in the pastures has increased. Output of N in milk and meat was almost equal to the prognosis. As the fat content of the milk generally was below the reference value, a larger volume of milk could be sold.

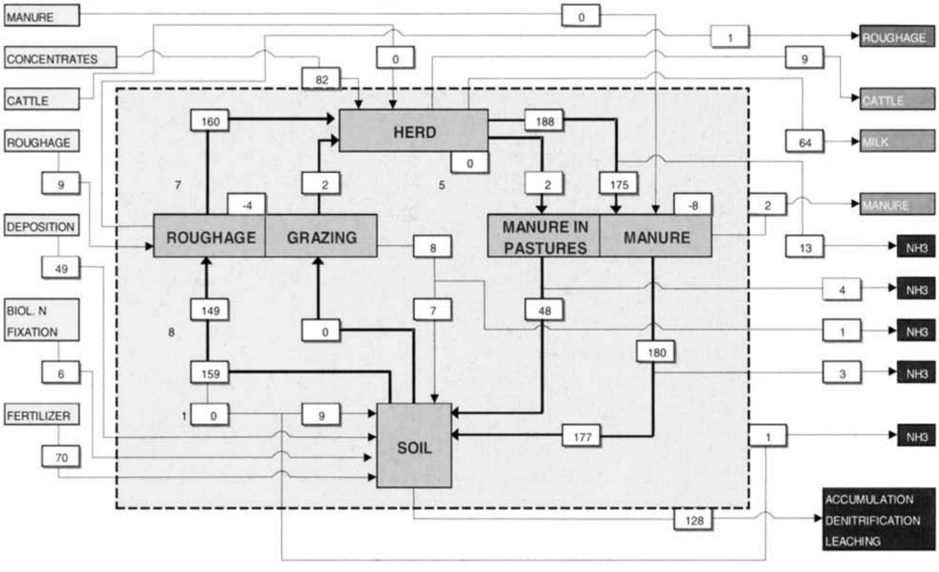

Figure 1. Nitrogen cycle (kg N ha^{-1}) of experimental farm 'De Marke' averaged over the period 1993/1994-1998/1999.

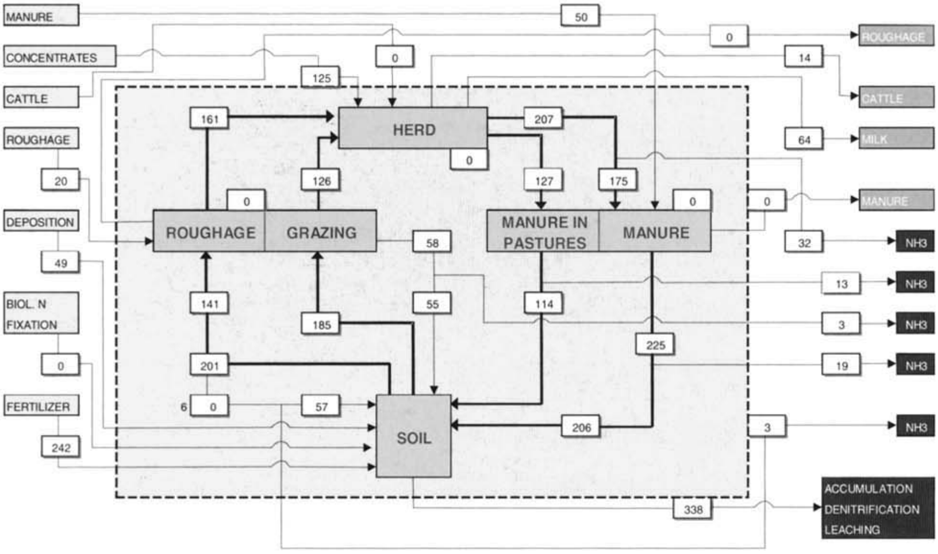

Figure 2. Nitrogen cycle (kg N ha^{-1}) of a 'current average' farm (see text for explanation) on sandy soil in the middle of the 1990s with the same milk quotum as that of 'De Marke'.

Comparison of the N balance of 'De Marke' with that of the 'current average' farm shows that at 'De Marke' less fertilizer and feed were purchased. In other words, the realization of very high N utilization efficiencies in animal nutrition and crop cultivation allows a similar milk production at a much lower input level. This can be considered the most important characteristic of the farming system 'De Marke'.

Components herd and manure

The N balance of the component herd (Table 8) shows that total input on the 'current average' farm substantially exceeded that of 'De Marke' (412 versus 313 kg N ha^{-1}, respectively), both in concentrates (125 versus 82 kg ha^{-1}, respectively) and roughage (287 versus 232 kg N ha^{-1}, respectively). This higher N input did not result in a higher milk and meat output, but in a much higher N excretion in manure (334 versus 240 kg N ha^{-1}, respectively).

In the prognosis for 'De Marke', the efficiency of N utilization for the conversion of feed into meat and milk was set at 25%. This figure was based on a ration low in protein, a high milk production per animal, and a relatively small number of young stock as N utilization efficiency in young stock is very low. The realized utilization efficiency over the period 1993–1998 was 23%, compared with 19% on the 'current average' farm. This lower utilization efficiency results in a 27% higher N excretion in manure and urine. The quantity of N entering the slurry storage at 'De Marke' was virtually identical to the one on the 'current average' farm (175 kg ha^{-1}), because of the shorter grazing time (less excretion during grazing) and the low-emission stable. The latter led to volatilization losses of 13 kg N ha^{-1} or 7.5% at 'De

Table 7. Nitrogen balance (kg N ha^{-1}) of 'De Marke' for the fiscal years '93/'94 – '98/'99, the prognoses at the start of the farm, and the balance of the 'current average' farm (see text for explanation) in the middle of the 1990s.

	Prognosis	'93/'94	'94/'95	'95/'96	'96/'97	'97/'98	'98/'99	Average '93-'98	'Current average' around '95
A. INPUT									
Concentrates	41	82	70	75	86	73	101	81	125
Roughage	0	2	11	8	12	10	10	9	20
Chemical fertilizer	67	53	96	75	52	63	78	70	242
Organic manure	0	0	0	0	0	0	0	0	50
Clover	30	12	5	8	3	4	4	6	0
Animals	0	1	0	0	0	0	0	0	0
Deposition	49	49	49	49	49	49	49	49	49
Miscellaneous	5	4	4	5	5	5	5	5	0
Total	192	203	235	220	207	204	247	219	486
B. OUPUT									
Milk	62	65	64	62	66	63	67	65	64
Animals	8	11	9	10	8	7	7	9	14
Roughage	0	8	0	0	0	0	0	1	0
Organic manure	0	0	0	0	0	7	7	2	0
Total	70	84	73	72	74	77	81	77	78
C. CHANGE IN STOCKS									
Animals	0	0	0	–2	–1	1	2	0	0
Roughage	0	–35	17	–20	–7	11	–4	–6	0
Concentrates	0	2	–3	0	4	–5	3	0	0
Organic manure	0	11	–50	5	20	–31	1	–7	0
Total	0	–22	–36	–17	16	–24	2	–14	0
SURPLUS (A-B-C)	122	141	198	165	117	151	164	156	408

Marke', against 32 kg or 17% on the 'current average' farm. The difference between input and output in the component manure (Table 9) represents volatilization losses in the stable, and during grazing, storage and application. On the 'current average' farm, total volatilization losses are 64 kg ha^{-1}, compared with 20 kg ha^{-1} calculated for 'De Marke' using estimated loss fractions. If measured loss fractions are used, total ammonia loss in 1999 was 25 kg ha^{-1} (Van Der Schans *et al.*, 1999).

Components soil and crop

Total N supply to the soil at 'De Marke' was on average equal to the prognosis (Table 10), whereas on the 'current average' farm it was almost twice as high (723 versus 367 kg ha^{-1}). Especially the inputs in fertilizer, manure during grazing, and net grazing losses were much higher.

Production of manure in the pasture was substantially lower at 'De Marke' than on the 'current average' farm. The spatial distribution pattern of this manure is so unfavourable that grass hardly profits from its N. Moreover, the use of fertilizer was substantially lower.

Table 8. Nitrogen balance (kg N ha^{-1}) of the component herd of 'De Marke' for the fiscal years '93/'94 – '98/'99, the prognoses at the start of the farm and the balance of the 'current average' farm (see text for explanation) in the middle of the 1990s.

	Prog-nosis	'93/'94	'94/'95	'95/'96	'96/'97	'97/'98	'98/'99	Aver-age '93-'98	'Current average' around '95
INPUT									
Concentrates	41	80	73	76	84	79	100	82	125
Roughage + grass	237	256	257	229	228	202	217	232	287
Total	278	336	329	305	312	282	317	313	412
OUTPUT									
Milk	62	65	64	62	66	63	67	64	64
Meat	8	11	9	9	8	8	10	9	14
Excretion in pasture	56	52	62	46	38	53	63	52	127
Excretion in stable	152	209	194	188	200	158	176	188	207
Total	278	337	329	305	312	282	317	314	412
Output in milk and meat (% of input)	25	23	22	23	24	25	24	23	19

Table 9. Nitrogen balance (kg N ha^{-1}) of the component manure of 'De Marke' for the fiscal years '93/'94 – '98/'99, the prognoses at the start of the farm and the balance of the 'current average' farm (see text for explanation) farm in the middle of the 1990s.

	Prog-nosis	'93/'94	'94/'95	'95/'96	'96/'97	'97/'98	'98/'99	Aver-age '93-'98	'Current average' around '95
INPUT									
Excretion in pasture	56	52	62	46	38	53	63	52	127
Excretion in stable	152	209	194	188	200	158	176	188	207
Input in organic manure	0	0	0	0	0	0	0	0	50
Total	208	261	256	234	238	211	240	240	384
OUTPUT									
Manure at pasture	51	48	57	42	35	49	59	48	114
Organic manure	137	182	227	166	164	168	154	177	206
Export organic manure	0	0	0	0	0	7	7	2	0
Change in stock of manure	0	11	–50	5	20	–31	1	–8	0
Total	188	241	234	214	218	193	220	220	320
INPUT – OUTPUT[1]	18	20	23	20	20	18	19	20	64
% output of input	91	92	91	91	92	91	92	92	83

[1] Ammonia volatilization from manure.

Table 10. Nitrogen balance (N kg ha^{-1}) of the component soil of 'De Marke' for the fiscal years '93/'94 – '98/'99, the prognoses at the start of the farm and the balance of the 'current average' farm (see text for explanation) farm in the middle of the 1990s.

	Prog-nosis	'93/'94	'94/'95	'95/'96	'96/'97	'97/'98	'98/'99	Aver-age '93-'98	'Current average' around '95
INPUT									
Manure in pasture	51	48	57	42	35	49	59	48	114
Organic manure[1]	137	182	227	166	164	168	154	177	206
Chemical fertilizer	67	52	96	75	52	63	79	70	242
Deposition	49	49	49	49	49	49	49	49	49
Net feeding losses[2]	21	18	20	17	14	15	16	17	112
Clover	30	12	5	8	3	4	4	6	0
Total	355	361	454	359	316	348	361	367	723
OUTPUT									
Gross crop	276	275	269	233	216	219	218	238	386
INPUT – OUTPUT[3]	79	86	184	126	100	129	142	128	338
% output of input	78	76	59	65	68	63	61	65	53

[1] Slurry (faeces + urine) following ammonia volatilization.
[2] Cutting and grazing losses following ammonia volatilization.
[3] Input – output = accumulation in organic matter, denitrification and leaching.

Total N in gross crop production (Table 11) at 'De Marke' (238 kg ha^{-1}) was lower than expected (276 kg ha^{-1}). Especially in the last years before 1999, gross crop yields were lower than expected. One of the reasons for the much higher N yields (386 versus 238 kg ha^{-1}) on 'current average' farms is the combination of a higher proportion of grass in the rotation and a higher chemical fertilizer dose. However, the N utilization efficiency at 'De Marke' was 65% against 53% on the 'current average' farm. The consequence is that 'residual' N (N not recovered in feed) was much lower (128 versus 338 kg ha^{-1}) than on the 'current average' farm. This N was incorporated in soil organic matter, or lost through denitrification or leaching.

Unavoidable losses taking place during cutting and grazing were about 10% at 'De Marke', and about 30% on the 'current average' farm (Table 11). A small proportion of these losses is due to ammonia volatilization, the remainder is recycled to the soil (net feeding losses, Table 10). So net N losses from feeding were lower at 'De Marke'. N utilization efficiency for the crops was higher (93 versus 71%), mainly as a result of lower grazing losses owing to short grazing periods per plot, night stabling, a short grazing season, and young stock following the dairy herd at pasture.

Additional environmental effects

The objective of reducing annual ammonia losses from animal manure to 30 kg ha^{-1} was attained (Van Der Schans *et al.*, 1999). Ammonia emission calculated for 'De Marke' was 70% lower than for the 'current average' farm in the 1980s. For the sta-

Table 11. Nitrogen balance (kg N ha^{-1}) of the component crop of 'De Marke' for the fiscal years '93/'94 – '98/'99, the prognoses at the start of the farm and the balance of the 'current average' farm (see text for explanation) farm in the middle of the 1990s.

	Prog-nosis	'93/'94	'94/'95	'95/'96	'96/'97	'97/'98	'98/'99	Aver-age '93-'98	'Current average' around '95
INPUT									
Gross production pasture grass	106	86	101	81	67	71	72	80	185
Gross production roughage	170	189	169	151	148	148	146	159	201
Purchase roughage	0	2	11	8	12	10	10	9	20
Total	276	277	280	241	227	229	228	247	406
OUTPUT									
Uptake pasture grass	93	77	91	73	61	64	65	72	126
Uptake roughage	144	179	166	156	168	138	152	160	161
Sale roughage	0	8	0	0	0	0	0	1	0
Change in stock of roughage	0	–8	2	–7	–15	11	–6	–4	0
Total	237	256	259	222	213	213	211	229	287
INPUT – OUTPUT[1]	39	21	21	19	15	16	18	18	119
% output of input	86	92	92	92	94	93	92	93	71

[1] Grazing-, harvest-, conservation- and feeding losses.

ble and storage facilities, measured emission factors have been used. For the losses during application and grazing, emission factors were estimated.

Annual emission from the stable was very similar to the value calculated in the design phase: 9.8 kg ha^{-1}. If the emission fraction had been equal to the one on the 'current average' farm, losses would have been 14.5 kg ha^{-1} higher. Emission following slurry application to grassland was higher than expected. Slurry injection on arable land satisfied the norms (Van Der Schans *et al.*, 1999). The largest ammonia 'leak' on 'De Marke' resulted from application to grassland. If ammonia emission is to be further reduced, this practice offers scope for improvements.

Average annual P surplus was 6 kg ha^{-1}. The surplus calculated according to MINAS (MINeral Accounting System; Van Den Brandt & Smit, 1998) was 0. This is substantially below the final MINAS target of 20 kg ha^{-1}. In the MINAS-balance for 'De Marke', P input equals output. Input in chemical fertilizers was almost 0, but in concentrates it was about twice the expected value. In the prognosis, 14 kg P ha^{-1} in chemical fertilizer and 14 kg P ha^{-1} in concentrates were expected. Average annual input during the period 1993–1998 was 1 kg P ha^{-1} in fertilizers and 27 P kg ha^{-1} in concentrate. If the input in concentrate cannot be substantially reduced, there is no scope for the application of chemical fertilizers.

Between 1989 and 1995 the average amount of available P (Pw) (Van Der Paauw, 1956) decreased with 26%, especially on plots with high initial values (Habekotté *et al.*, 1999). However, on all plots the P status still is agronomically 'sufficient' or higher. After 1995 the average P status did not further decrease, and at the current value no problems are expected from an agronomic point of view. Over the last years total P in the soil hardly changed.

If on all plots a P surplus of 1 kg ha^{-1} can be realized, it will take 10 to 40 years – according to model calculations – before plots currently with a status 'sufficient' will reach the status 'low' (Schoumans, 1998). Eventually, the P status of the soils at 'De Marke' will stabilize, but as yet it is not clear at what level.

Conclusions

1. Over the period 1993/1994–1998/1999 the average N surplus at 'De Marke' was 156 kg ha^{-1}. In short, the target of 128 kg ha^{-1} has not been realized (yet).
2. N input at 'De Marke' via concentrates was twice the expected value; input via chemical fertilizers and clover was lower than expected.
3. The expected N utilization efficiency of 25% for the conversion of feed into milk and meat was not yet attained. As a result, N excretion in the slurry was too high. However, with 23% this efficiency was much higher than for the 'current average' farm.
4. On the 'current average' farm, N losses via ammonia volatilization were 64 kg ha^{-1}. At 'De Marke' this has been reduced to 20 kg ha^{-1} owing to the low-emission stable, and the restricted grazing time. If measured instead of estimated loss fractions were used, the ammonia emission in 1999 amounted to 25 kg ha^{-1}.
5. The norm for ammonia emission from organic manure (30 kg N ha^{-1}) was met.
6. Total crop yields (pasture grass, grass silage and silage maize) at 'De Marke' were lower than expected.
7. For the gross crop yields at 'De Marke' the utilization efficiency of total N applied to the soil was 65% against 53% for the 'current average' farm.
8. Utilization efficiency of crop N at 'De Marke' was 93%, which is much higher than the 71% for the 'current average' farm. This is explained by the lower grazing losses resulting from the short grazing periods, the short grazing season, and the young stock grazing the residual grass left by the dairy herd.

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