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Efficient resource management in dairy farming on sandy soil

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Abstract

Sandy soils in the Netherlands are mainly used for dairy farming. As a result of intensification of dairy farming in the recent past, valued functions of sandy regions now are threatened by high emissions of nitrogen (N) and phosphorus (P) and by increased water consumption by forage crops. Improved utilisation efficiency of resources is proposed as a strategy to realise environmental targets in an economically attractive way. Experimental results of the prototype system 'De Marke' indicate that an average intensive commercial farm can halve inputs of fertilisers and feeds at least, without the need to reduce milk production per hectare or to export slurry. Besides, water consumption can be reduced by 13%, increasing groundwater 'production' by 570 m^3 ha^{-1}. Nitrate concentration in the upper groundwater decreased from 200 to 50 mg l^{-1}. Changes in soil fertility did not lead to serious agricultural problems but costs of milk production increased by 5%. However, additional costs probably can be compensated if the extra groundwater is 'harvested' by water companies, because of high cost of purification of surface water and consumer preference for drinking groundwater instead of water from rivers. In 1999, the examined strategy of improved resource management will be implemented on 12 commercial farms, representing the full range of conditions for dairy farming in the Netherlands.

Keywords: resources, nitrogen, N, nitrate, ammonia, phosphorus, P, dairy farming, systems research, environment, sandy soils, groundwater, leaching

Introduction

The sandy soils in the Netherlands are mainly used for forage production for dairy cattle, with 520,000 ha perennial ryegrass (*Lolium perenne* L.) and 180,000 ha silage maize (*Zea mays* L.) as main crops, representing 82% of the cultivated area. Sandy regions are also important for collecting groundwater, as a source of drinking water for human consumption. Moreover, many valuable nature reserves are located in the sandy areas and recreation has become an important source of income.

From the 1960's onwards, farms strongly intensified milk production by increasing inputs of fertilisers, concentrates and (irrigation) water. In 1984, introduction of the milk quota system in the European Union stopped that process. Current milk production on sandy soils is 12,400 kg ha^{-1} yr^{-1}, 500 kg above the national average and high compared to most other European countries (Beldman & Prins, 1999). As a result of intensification, valued functions of sandy regions are threatened by emissions of nitrogen (N) and phosphorus (P) and lowered groundwater levels. Farm nutrient outputs in milk and meat represent on average only 16 (N) and 27% (P) of inputs, mainly in purchased feeds and fertilisers. The surpluses of about 400 kg N and 40 kg P $ha^{-1}yr^{-1}$ contribute to environmental pollution by emissions of ammonia and nitrous oxide (N_2O) to the air, and nitrate and phosphate to the water.

As a consequence, for instance, nitrate concentrations in the shallow groundwater of the sandy regions exceed the standard (50 mg l^{-1}) of the 1980 EU Drinking Water Quality Directive by a factor of up to five (Fraters *et al.*, 1998). As the quantity of extractable groundwater for human consumption became limited, additional water from the rivers Rhine and Meuse has to be purified, at high costs.

To be sustainable, livestock production systems must provide adequate income for farmers, in a way that is acceptable to society. In particular, there is demand for a clean and attractive environment and for efficient use of resources, particularly non-renewable resources such as fossil energy, and resources for which alternative demands exist, such as groundwater. Dairy farms could probably meet environmental standards through extensification, i.e. by expanding farm size to reduce milk production intensity per hectare. However, land is very expensive and therefore extensive farming probably will not be sustainable from an economic point of view. Moreover, a societal demand exists for alternative use of available land, like expanding nature reserves. Export of slurry, to increase farm output of nutrients, is also expensive and may lead to environmental problems elsewhere. Improved resource management, associated with reduced inputs of fertilisers, water and concentrates, would be the most attractive option. To investigate the feasibility of such a strategy, farm systems research was started in 1988, including validation of a prototype system, in theory meeting strict environmental goals, on an experimental farm, called 'De Marke'. This paper summarises the main results of that prototype system and discusses their significance for the opportunities of dairy farming. Results are compared with those of a current commercial farm with a comparable intensity of milk production. Research methodology, data collection methods, detailed results and comparison of farm performance with predicted performance based on model calculations, are described in detail elsewhere (Aarts *et al.*, 1992; Aarts *et al.*, 1999a,b; 22 'De Marke'–reports).

Methods and materials

Research approach

Characteristic for dairy farming systems is the combination of plant and animal production. By exchanging manure and forage between the plant and animal components, nutrients cycle through the system, leading to losses to air and water. Single nutrient flows can be influenced, but intervening in one may affect flows elsewhere in the cycle. Because of these interactions, whole farm research is needed for identification of attractive sets of measures, leading to substantial reductions in losses (Jarvis *et al.*, 1996). However, that presents two major methodological problems: (a) replicates are hardly possible, because of specific farm conditions, and (b) these specific conditions hamper extrapolation of results to other farms.

An attractive solution to these problems is to combine system modelling and system prototyping. Modelling is used to combine knowledge and to generate systems that, in theory, realise the identified system objectives for an average intensive dairy farm on sandy soil. Implementation in practice (prototyping) of one of these theoretical systems provides the opportunity to test the formulated hypotheses and validate the model results on which system design was based. Besides, a prototype can be demonstrated to and discussed with farmers during visits, stimulating introduction of improvements on commercial farms and generating new ideas for improvement of the prototype.

Since the prototype system is unique, results cannot be evaluated statistically in the conventional way. Therefore, results of an extensive monitoring program and of additional disciplinary research have been used to understand the functioning of the experimental system and to evaluate the quality of the underlying models. Improved models can be used as a tool to support adaptation of commercial farms.

System objectives

The environmental goals to be realised in the prototype system are more ambitious than those formulated in government legislation for introduction until the year 2008 (Van Den Brand & Smit, 1998). The main reasons are that the latter do not absolutely guarantee the desired quality of the environment in regions with light sandy soils. Moreover, imaginable agricultural problems associated with realising environmental goals, like a decrease in soil fertility, will come to the fore earlier and more pronounced.

In accordance with the1980 EU Drinking Water Quality Directive, a maximum of 50 mg nitrate l^{-1} in the upper groundwater was selected, a reduction of about 75% compared to the current situation in sandy areas (Table 1). Ammonia emissions from faeces and urine should not exceed 30 kg N ha^{-1}, about 50% of the current average. Emission of nitrous oxide should be reduced from 9 to 3 kg N ha^{-1}. Total farm surpluses should not exceed 128 kg N ha^{-1} and 0.45 kg P ha^{-1}. All manure should be applied on the farmland, so export of slurry to increase output of nutrients is not permitted.

Table 1. System objectives with regard to nutrients.

Objective	Maximum value
Nitrate leaching	50 mg nitrate l^{-1} in upper ground water
Ammonia volatilisation	30 kg N ha^{-1} yr^{-1} from manure
Losses of nitrous oxide	3 kg N ha^{-1} yr^{-1}
N surplus	128 kg N ha^{-1} yr^{-1} as farm inputs (including deposition and fixation by clover) minus outputs, assuming no accumulation in soil organic matter
P leaching	0.15 mg P l^{-1} in upper ground water
P surplus	0.45 kg P ha^{-1} yr^{-1}, deposition included

The system aims at maximising ‘production’ of groundwater of high quality. Therefore, sprinkling is only acceptable in emergency situations, to prevent early death of the crop, with the consequence of high costs for reseeding. Besides, reseeding ‘permanent’ grassland can lead to excessive leaching of nitrate, as a result of mineralisation of the accumulated organic N in the upper soil layers. Moreover, sprinkling is permitted to guarantee fresh grass supply for restricted grazing, as grazing is desirable from the point of view of animal welfare. Use of herbicides is minimised through application of mechanical weed control and crop rotation. If chemical control is unavoidable, only ‘environmentally save’ herbicides are allowed.

Lay out of the prototype system

A prototype system was implemented at experimental farm ‘De Marke’. The 55 hectares of land were reclaimed from heather at the beginning of the 20th century. An upper layer of 25 to 30 cm with an organic matter content of 4.8 % overlies a layer of yellow sand, extremely low in organic matter (podzol soil). Groundwater depth is 1 to 3 m below soil surface, too deep for substantial capillary rise into the root zone. Close to the farm, 5 Mm^3 groundwater is extracted annually by a drinking water company.

The drought sensitive sandy soil location was selected deliberately by involved scientists, as environmental problems tend to be most prominent here, and efficient management of nutrients and water most difficult. In 1989 the land was acquired and it has been used since as intended. However, until 1992 no cattle were present and no organic fertilisers were used.

As shown in Table 2, the proportion of grassland in the prototype system is smaller than on the current commercial farm, and the proportion of maize consequently larger. The main reason is the demand for energy-rich feed with a low N content, to compensate for the rather high N contents of the grass products in the ration. Moreover, the water and fertiliser requirements per unit harvestable dry matter of grass are much higher than of maize (Aarts *et al.*, 1996). Nevertheless, also at ‘De Marke’ the area of grassland exceeds that of maize, because grass can be grazed and can utilise more animal manure as it takes up nutrients in larger quantities than maize.

Table 2. Main characteristics of prototype system 'De Marke' and of a commercial farm with a comparable intensity of milk production (1994–1997).

	'De Marke'	Commercial farm
Cattle		
– milk per cow (kg yr^{-1})	8,200	7,250
– cows ha^{-1}	1.45	1.64
– young stock ha^{-1}	1.0	1.5
– grazing season	1/5 – 1/10	1/5 – 1/11
– daily grazing (hours, average season)	8	14
Soil and crops		
– grassland (%)	55	75
– maize land (%)	45	25
– crop rotation	Yes	No
– catch crop after maize	Yes	No

The farm area is divided in permanent grassland (close to the farm buildings, convenient because cows are kept indoors during parts of the day) and two crop rotations; crop rotation I, at only a short distance from the buildings, and rotation II further away. In crop rotation I, a three-year grassland period is followed by three years arable cropping, in crop rotation II by five. In the first year after the grass period maize is not fertilised. In all years, Italian ryegrass is sown as a catch crop between the rows in June, to take up excess fertiliser and N mineralised after harvest of the maize. Moreover, it creates possibilities for grazing the maize land in autumn and spring.

Fertiliser N application is about 40% less than on commercial farms, and does not exceed 250 kg ha^{-1} for grassland and 100 kg for maize, including N from slurry, clover and the anticipated contribution of Italian ryegrass and grass sod after ploughing. Mineral N fertilisers are only applied on grassland, on average 124 kg ha^{-1} annually. About 75 % of the slurry produced by the cattle is applied on grassland, on permanent grassland annually on average 49 m^3 ha^{-1} (24 kg P and 90 kg plant available N), on rotational grassland 72 (37 kg P and 133 kg N). Maize receives on average 26 m^3 ha^{-1} (12 kg P and 58 kg N). No fertilisers are applied between 15th August and 1st March, because of the risk of nitrate leaching due to the precipitation surplus and low crop demand.

Farm milk quota is 658,000 kg yr^{-1} (11,890 kg ha^{-1} yr^{-1}). Annual milk yield per cow is considerable higher than on the commercial farm. As a result, per unit of milk less feed is required, and the number of young stock for the replacement of cows is less as well. Composition of the feed rations aims at maximising utilisation of N in the feed for milk and weight gain, to reduce potential losses from manure (Paul *et al.*, 1998). In summer, dairy cattle are allowed limited grazing for two periods each day, with an intermediate resting period indoors ('siesta grazing'). During this period, cows are fed silage maize. This results in a more even distribution of high (grass) and low (maize) protein products over the 24-hour period, and a lower number of urine patches in the pasture. A short-duration rotational grazing system is practised (to reduce grazing losses) and early housing, i.e. 1st October at the latest, one month earlier than on commercial farms (to limit losses from urine patches). To restrict ammonia losses indoors, residence time of excreta outside the closed storage is minimised by frequent use of a dung scraper.

Data collection and data analyses

Where feasible, mass flows (like harvested crop material, applied slurry, purchased concentrates and distributed forage) are quantified by weighing, related nutrient flows by chemical analyses of samples. Crop yields are determined per plot by weighing prior to silage making. Fresh grass consumption by cattle is calculated per plot by estimating standing biomass just before and directly after grazing, and taking into account growth during grazing.

At the end of the year, the upper groundwater is sampled by the National Institute of Public Health and Environment (RIVM) at 137 points from bore holes, extending to 0.8 m below the groundwater table (Fraters *et al.*, 1998). In 1989, and annually from 1994 onwards, soil samples of the rooted zone (0–30 cm) are taken in the winter period to determine nutrient contents and soil fertility status. For that purpose, the farm is divided in 51 blocks of about 1 ha each. Mineralisation is measured continuously, denitrification occasionally, on 6 plots of 400 m^2.

Feed intake indoors is measured by weighing all feed entering the stable. Quantities of nutrients excreted in the stable are determined as produced slurry volume multiplied by nutrient contents, corrected for volatilisation indoors. Ammonia volatilisation indoors is measured continuously, volatilisation during grazing or following slurry application occasionally, to check the emission factors derived from literature (Biewinga *et al.*, 1992; Leneman *et al.*, 1998). Nutrients in faeces and urine, excreted during grazing, are estimated from the input in feeds by subtracting output in milk and meat and excretion indoors.

Performance of the prototype system is compared with that of a hypothetical commercial farm on sandy soil with a comparable intensity of milk production, derived from recent studies (Daatselaar *et al.*, 1998; Fraters *et al.*, 1997; Anonymous, 1998). In general, system characteristics of that farm are similar to the averages of characteristics of dairy farms on sandy soils, as derived from statistical surveys (Beldman & Prins, 1999).

Results

External resources

The gap between cattle feed requirements and net crop yields has to be filled by purchased feeds. Results of field trials have shown that yields are 8–10% below those of crops, fertilised in accordance with standards for a commercial farm. However, because of reduced grazing and conservation losses and because of a larger maize area (maize yields are higher than grass yields), average net crop yields (intake by cattle)

Table 3 . External resources, used by the prototype system 'De Marke', and reductions compared to the commercial farm (1994–1997).

	Input	Reduction (%)
Mineral fertilizer-N (kg ha^{-1})	69	71
Mineral fertilizer-P (kg ha^{-1})	0	100
Purchased feed (kg dry matter ha^{-1})	2,015	58
Water consumed by crops (m^3 ha^{-1})	3,670	13
Energy, direct (MJ ha^{-1})	11,020	–9
Energy, indirect (MJ ha^{-1})	33,060	58

were even higher. Combined with lower feed requirements, due to lower numbers of milking cows and young stock, purchases of feeds could be reduced greatly (Table 3). Feed requirements were covered for about 84% by home-grown feeds, compared to 64% on the commercial farm.

Input in purchased N fertilisers could be reduced by 71%, as a result of more efficient utilisation of 'home-made' fertilisers, reduced fertilisation levels and an increased maize area. The use of external P-fertilisers could be avoided completely from 1994 onwards. Reduced inputs of feeds and fertilisers also resulted in lower inputs of heavy metals. As a result, annual surpluses of copper (Cu), cadmium (Cd) and zinc (Zn) on the experimental farm were –7, –1.1 and 96 g ha^{-1}, respectively, compared to 25, 1.2 and 130 g ha^{-1} on the commercial farm.

Permanent grassland and grassland in crop rotation I were irrigated, mostly four times a year, with on average 96 mm water (960 m^3 ha^{-1}), maize with only 20 mm. Mainly because of a reduced area grassland, restricted fertilisation and restricted irrigation at 'De Marke' (crop rotation II was not irrigated at all), estimated average water consumption was 57 mm (570 m^3 ha^{-1}) lower than at the commercial farm (Aarts *et al.*, 1999c).

Direct energy consumption (as fuel and electricity) exceeded that of the commercial farm. This is mainly due to mechanical weed control, additional soil cultivation (temporary grassland), and the use of a dung scraper. However, indirect energy consumption is low, because of lower needs for purchased fertilisers and feeds. As a result, total energy consumption was reduced by 50%.

Nutrient surpluses

As shown in Table 4, prototype system 'De Marke' realised much lower nutrient surpluses than the commercial farm, mainly because of lower inputs by fertilisers and feeds. Lower output in meat was due to the lower number of animals. N surplus was 62% below that of the commercial farm, P surplus even 94%. Even so, surpluses still exceed acceptable maximum levels and have to be reduced further in the coming years. As a result of considerably reduced inputs and only slightly reduced outputs, efficiency of the farming system, defined as output divided by input, increased strongly.

Table 4. Nutrient balances (kg ha^{-1} yr^{-1}) realised for prototype system 'De Marke' and for the commercial farm (1994 – 1997).

	Commercial farm		'De Marke'	
	N	P	N	P
Input:				
Concentrates	125.0	21.5	78.1	11.8
Forage	20.0	1.0	17.6	2.1
Mineral fertilizer	241.5	18.0	68.9	0.0
Organic fertilizer	50.0	12.5	0.0	0.0
Deposition	49.0	0.9	49.0	0.9
Others	0.0	0.0	12.7	0.9
Sum	*485.5*	*53.9*	*226.3*	*15.7*
Output:				
Milk	64.2	10.5	64.2	10.5
Cattle	14.0	4.1	8.9	2.7
Sum	*78.2*	*14.6*	*73.1*	*13.2*
Surplus	*407.3*	*39.3*	*153.2*	*2.5*
Efficiency (output/input)	*16%*	*27%*	*32%*	*84%*

Nitrogen cycle

The main N flows in system 'De Marke' and in the commercial system are presented in Figures 1 and 2. N in feed is used more efficiently at 'De Marke': about 23% of N consumed as concentrates, roughage and fresh grass is recovered in milk and meat, compared to 19% on the commercial farm. Minimum N requirements of lactating cows were exceeded by 3% (summer) and 8% (winter), of non-lactating cows by 39% (summer and winter) and of young stock by 180 and 36% in summer and winter, respectively (Van Der Schans, 1998). This is due to very low N requirements (non-lactating cows and young stock), continuous grazing (young stock) and the limited possibilities for individual feeding. Nevertheless, there is still scope for further reductions in the N surplus in the diet of the cattle. By restricting annual grazing time to about one third of that in commercial systems, excretion of N at pasture was with 50 kg ha^{-1} on average 20% of the total (50 kg at pasture + 197 kg indoors), compared to 38% on commercial farms. In total, 21 kg N ha^{-1} was lost as ammonia from excreta (13 kg from the stable + 4 kg from slurry after application + 4 kg from excreta produced during grazing), well below the maximum acceptable level of 30 kg and 67% below the level of the commercial farm (32 kg from the stable + 19 kg from slurry + 13 kg from grazing = 64 kg).

Total N supply to the soil, including lost forage caused by grazing (9 kg not consumed – 1 kg ammonia volatilisation = 8 kg return) and harvesting (10 kg – 1 kg = 9 kg), was 52% of that on a commercial farm. About 62% of the total soil input origi-

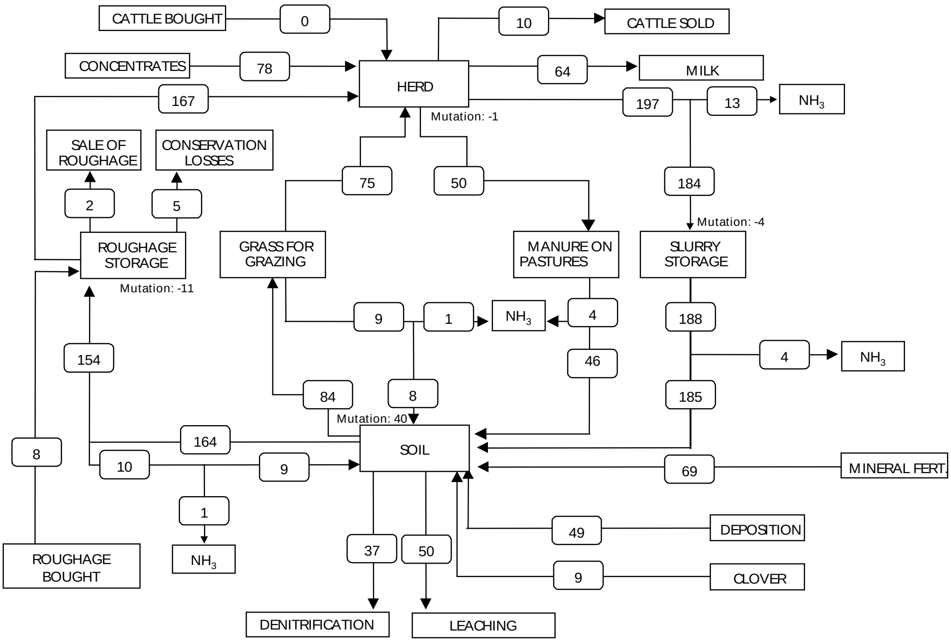

Figure 1. Nitrogen cycle of prototype system 'De Marke' (1993–1997, kg N ha^{-1}).

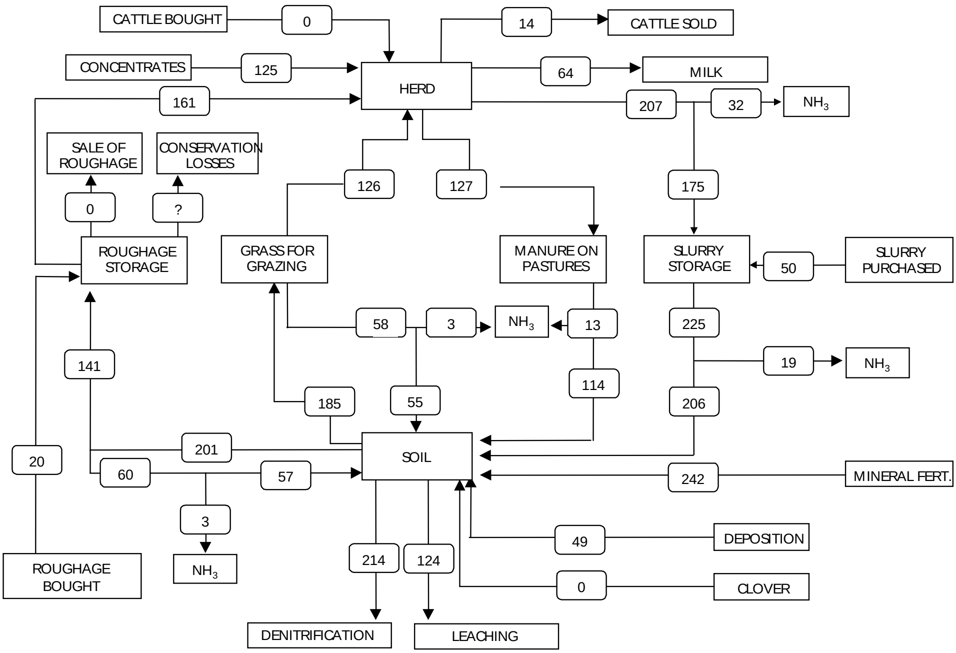

Figure 2. Nitrogen cycle of a commercial farm on sandy soil (1994–1997; kg N ha^{-1}).

nated from excreta, compared to 44% at the commercial farm. N-contents of fresh grass (38 g kg^{-1} dry matter), grass silage (29 g) and maize silage (12 g) were 9 – 11% below those of crops grown on a commercial farm. Average yield of N per hectare was considerably lower, mainly because more land was used to grow maize. On average, 127 kg ha^{-1} of the N supplied to the soil was not recovered in the harvestable products (164 kg as roughage + 84 kg as grass for grazing), compared with 337 kg on the commercial farm. As a result, the efficiency of the soil/crop component of the 'De Marke' system was 66%, compared to 53% on the commercial farm. Estimated emission of N_2O on 'De Marke' was 5 kg ha^{-1}, on a commercial farm 9 kg ha^{-1}, mainly related to denitrification (Velthof & Oenema, 1997).

Slurry and roughage production in a particular year are not necessarily similar to slurry application and forage consumption, for instance because of weather conditions. That will cause mutations in the quantity of N stored as roughage and slurry. Also the quantity of N stored in cattle can vary a little from year to year. However, averaged over a long period mutations will be negligible.

Groundwater quality

Table 5 shows nitrate concentrations in the upper groundwater for fields that have been in use since 1989. The rapid fall to levels around the upper limit for nitrate (50 mg l^{-1}) is striking. In 1997, the concentration was again somewhat above that level. Nitrogen concentrations are the result of the combined effect of N quantities and quantities of water. The wet winters of 1993 and 1994 will have resulted in low concentrations, mainly due to dilution, although high rainfall does not always result in lower concentrations. A period of high precipitation in early summer of 1997 probably caused leaching of fertiliser, because of a restricted time for crop uptake. In addition, high rainfall during the growing season may have resulted in accelerated breakdown of organic material that contains N. The effect of land use on nitrate concentration is shown in Table 6. The alarmingly high values for permanent grassland and grassland in rotation I is probably due to intensive grazing on those fields. The 'safe' nitrate concentrations for the less intensively grazed grassland of rotation II and for maize are more or less equal. Average P content in the upper groundwater at 'De Marke' was 0.01–0.06 mg l^{-1} and therefore in all years far below the maximum acceptable value (0.15 mg l^{-1}).

Table 5. Time course of nitrate concentration (mg l^{-1}) of the upper groundwater of prototype system 'De Marke'.

	1990	1992	1993	1994	1995	1996	1997
Permanent grassland	159	80	50	43	60	52	96
Rotation I	220	117	43	46	54	36	49
Rotation II	181	104	53	35	35	20	47
Farm	*199*	*107*	*47*	*43*	*51*	*35*	*57*

Table 6. Average concentration of nitrate (mg l^{-1}) in the upper groundwater below grass and maize of prototype system 'De Marke' (1995–1997).

	Grass	Maize
Permanent grassland	71	–
Crop rotation I	49	39
Crop rotation II	36	42
Average	*55*	*40*

Soil characteristics and crop production

Results of soil analyses suggest an average increase in organic N (N-total) with 1 mg per 100 g dry soil annually, corresponding with about 40 kg N $ha^{-1}yr^{-1}$ (Table 7). Differences in net mineralisation of up to 90 kg N ha^{-1} yr^{-1} were found among years. In general, mineralisation was positively correlated with rainfall during the growing season. As organic matter content remained essentially constant, C:N ratio decreased from 19.6 in 1989 to 17.4 in 1997, assuming organic matter contains 58% C.

Soil P-fertility status, expressed as P-Al (ammonium lactate extractable phosphate; Van Der Paauw, 1956), decreased until 1995, by on average 15%. As P-total hardly decreased, P solubility must have declined. From 1995 onwards, P-Al stabilised at levels considered sufficient from an agricultural point of view (Aarts *et al.*, 1999a). Although N defiency reduced yields of maize and grass to about 90–92% of those obtained at commercial farms, the major yield determining factor at 'De Marke' is availability of water (Habekotté & Hilhorst, 1998). In the period 1993–1998 annual average crop yields varied between 8,000 and 10,100 kg dry matter ha^{-1} for grass (with 9,200 kg as average) and between 9,000 and 12,000 kg for maize (with 10,600 kg as average).

Economics

As shown in Table 8, realisation of the strict environmental goals at the prototype system increased costs of milk production by 4.8 cents (0.02 EURO) to 90.1 cents kg^{-1} (De Haan & Mandersloot, 1998). Especially contractor costs were higher, mainly due to reduced grazing (more silage produced and more slurry to be applied) and crop rotation (establishing temporary grassland). Also adapted housing (stable with

Table 7. Average soil characteristics (0–30 cm; mg per 100 g dry soil, for organic matter g per 100 g dry soil; P-total and P-Al as usual expressed as P_2O_5).

	1989	1994	1995	1996	1997
Organic matter	4.8	4.9	4.8	4.6	4.7
N-total	142	144	138	149	157
P-total	169	165	166	162	164
P-Al	75	69	64	65	65

Table 8. Additional costs of milk production (cents kg^{-1} milk) of prototype system 'De Marke', due to strict environmental goals (based on De Haan & Mandersloot, 1998).

	Additional costs
Labor farmer	0.6
Contractor	2.3
Housing/equipment	2.6
Others	0.8
feed/fertiliser	–1.5
Total	*4.8*

low emission characteristics), an expanded slurry storage and additional equipment (mechanical weed control) increased costs. Labour requirements were higher, mainly because of restricted grazing (feeding cows indoors) and mechanical weed control. Savings on feeds and fertilisers only partially compensated these additional costs. Because a commercial farm produces about 360,000 kg milk annually, the decrease in income is considerable. Fortunately, a reduction in cost by further research is expected. Nevertheless, effects of environmental targets on farmers income deserves attention of society, as society harvests benefits.

Discussion

To reach definite conclusions, a much longer research period is needed, as obviously most of the characteristics of the prototype system are still in transition. However, the research results obtained so far, present indications, helpful in discussing possible development strategies for dairy farming.

How far can input of external resources be reduced by improved management, while maintaining intensity of milk production and soil fertility? Purchases of fertilisers and feeds were more than halved in the prototype system, compared to current farming systems. Reductions in purchased feeds, mainly because of more judicious feeding and a higher milk production per cow, decreased inputs of nutrients with 34% (N) and 38% (P). Purchases of organic and mineral fertilisers could be reduced by 76 (N) and 100% (P), as a result of improved utilisation of manure, reduced fertilisation levels and an increased maize area. Reduced crop yields, as a result of lower fertilisation levels, could be compensated by reduced conservation and grazing losses. Reduced irrigation and fertilisation and an increased maize area resulted in an average reduction in water consumption by crops of 570 m^3 ha^{-1}. Soil fertility changes did not negatively affect crop yields and serious problems are not expected. There is still scope for further reductions of the inputs of the prototype system.

Did improved resource management lead to the desired quality of the environment? Average nitrate contents in the upper groundwater decreased very rapidly from 200 to around 50 mg l^{-1}, the permitted upper limit. However, nitrate content seems to be above the acceptable level, if grassland is grazed rather intensively. Therefore, research should pay attention to identification of the maximum acceptable intensity for grazing. Moreover, above-average winter rainfall in the trial period may have contributed to the observed rapid decrease. Observations are contrary to model-calculated delayed response times of more than 20 years, due to the time needed to establish a new mineralization-immobilization equilibrium in the upper soil layers (Oenema & Roest, 1998).

The average realised surplus of 153 kg N $ha^{-1}yr^{-1}$ presumably consists of 21 kg ammonia-N from manure, 50 kg nitrate-N leached to groundwater, 40 kg accumulation in soil as organic-N, 37 kg N denitrified (including 5 kg nitrous oxide-N) and 5 kg losses (form unknown) during and after conservation of roughage. This surplus exceeds the target value (128 kg N ha^{-1} yr^{-1}), but accumulation as organic-N in the soil was not anticipated. The C:N ratio decreased from 19.6 in 1989 to 17.4 in 1997. Because C:N ratios in comparable (podzol) sandy soils are between 15 and 20 (Hassink, 1994) it is difficult to forcast when accumulation will stop.

Magnitude and direction of changes in the soil store strongly depend on moisture supply. Under more favourable soil moisture conditions, the rate of decomposition of organic material was higher. When the change in soil N store is not considered, a high N surplus in a dry year (causing an increase in soil N store and therefore deactivating surplus partially) can be less damaging to the environment than a low surplus in a wet year (causing a decrease in soil N store). The experimental period is still too short for estimating the influence of the farming system on the 'equilibrium-level' of the soil organic N store. That value is, however, important in determining the environmental impact of the farm surplus over a longer time period.

What are the financial costs and profits of realising environmental goals by improved utilisation of resources in dairy farming? Realising the strict environmental goals of the prototype system increased costs of milk production by 5% (0.02 EURO kg^{-1} milk and 240 EURO ha^{-1}). However, model calculations suggest that realising the less strict governmental goals for the period until 2002 could even be profitable, as the financial benefits of reduced inputs overcompensate the additional costs. Performance of high-quality commercial farms supports results of modelling, indicating that improved utilisation of resources can reduce surpluses by at least 30%, without increasing costs. However, such a reduction is insufficient in the long term, to guarantee the desired quality of the environment.

Costs for purification are 0.44 EURO per m^3 higher for surface water than for groundwater (pers. comm. L. Joosten, Netherlands Drinking Water Association). Hence, 250 EURO ha^{-1} can be saved, when the 570 m^3 water ha^{-1}, less consumed by the crops in the prototype system, is available for production of drinking water, substituting surface water. Besides, consumers prefer groundwater, instead of water from polluted rivers. These benefits exceeds the total costs of realising the strict environmental targets of the prototype system. In the Netherlands, average annual per capita water consumption is 50 m^3, i.e. the additional groundwater production of 570 m^3 ha^{-1}, realised at 'De Marke', can replace surface water for 11 individuals. At the farm size of 55 ha, more than 600 persons could profit from improved resource management if farmer is financially rewarded for.

Conclusions and perspectives

Research results of the prototype system suggest that, in principle, even on light sandy soils, strict environmental targets can be attained after a relatively short period of adaptation, while maintaining the current milk production intensity and without the need to export slurry at high costs. Improved resource management in all parts of the system is essential to realise the required reduction in purchased feeds and fertilisers. In the future, additional cost could be compensated by society to maintain farmers income on an acceptable level, justifiable because of increased groundwater 'production' or improved quality of nature.

Less strict environmental goals as formulated by the government for the next years permit above-average milk production intensities. However, management comparable to that of the experimental system requires very skilled farmers. Therefore, in a new research project ('Cows and Challenges'), 12 farmers will be strongly supported in adapting farm management, following the strategy of improved resource management and using the experiences of 'De Marke'. These farms represent the full range of conditions for dairy farming in the Netherlands, hence most Dutch farmers can identify themselves with one of those farmers. Already in 2002 these farms have to reduce the nutrient surpluses to the maximums, defined by the government for the year 2008.

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References

Aarts H.F.M., B. Habekotté & H. Van Keulen, 1999a. Phosphorus (P) management in the 'De Marke' dairy farming system. *Nutrient Cycling in Agroecosystems* (in press).

Aarts H.F.M., B. Habekotté & H. Van Keulen, 1999b. Nitrogen (N) management in the 'De Marke' dairy farming system. *Nutrient Cycling in Agroecosystems* (in press).

Aarts, H.F.M., C. Grashoff & H. Van Keulen, 1999c. Managing dairy farming systems for groundwater conservation in the sandy regions of the Netherlands. Report 101. Institute for Agrobiological and Soil Fertility Research (AB-DLO), Wageningen, 22 pp.

Aarts, H.F.M., C. Grashoff, & H. G. Smid, 1996. Evaluation of perennial ryegrass, lucerne, silage maize and fodder beets under drought. In: Parente G., J. Frame & S. Orsi (Eds.) Proceedings of the 16th meeting of the European Grassland Federation. Grassland Science in Europe. Vol. 1, British Grassland Society, Reading, United Kingdom pp. 363–366.

Aarts, H.F.M., E.E. Biewinga & H. Van Keulen, 1992. Dairy farming systems based on efficient nutrient management. *Netherlands Journal of Agricultural Science* 40: 285–299.

Anonymous, 1998. Manure and mineral production 1997 (in Dutch). Statistisch Bulletin 37, 24/9/98, Centraal Bureau voor de Statistiek (CBS), Voorburg.

Beldman, A.C.G. & H. Prins, 1999. Analysis of differences in mineral surpluses on specialised dairy farms (1996/1997) (in Dutch). Report 2.99.01. Agricultural Economics Institute (LEI-DLO), The Hague, 42 pp.

Biewinga, E.E., H.F.M. Aarts & R.A. Donker, 1992. Dairy farming under strict environmental norms (in Dutch), Report 1, 'De Marke', Hengelo, 284 pp.

Daatselaar, C.H.G., D.W. De Hoop, B.W. Zaalmink & T. De Haan, 1998. 'De Marke' and its target values for farm economics. Rapport 'De Marke' no. 21, Hengelo (in Dutch).

De Haan, M.H.A. & F. Mandersloot, 1998. Environmental goals 'De Marke' in economic perspective (in Dutch). Report 'De Marke', Hengelo.

Fraters, B., H.A. Vissenberg, L.M.J. Boumans, T. De Haan & D. W. De Hoop, 1997. Results of monitoring programme upper groundwater agricultural holdings in the sandy areas 1992–1995 (in Dutch). Report 714801014, National Institute of Public Health and Environment (RIVM), Bilthoven, 181 pp.

Fraters, D., L.M.J. Boumans, G. Van Drecht, T. De Haan & D.W. De Hoop, 1998. Nitrogen monitoring in groundwater in the sandy regions of the Netherlands. In: K.W. Van Der Hoek, J.W Erisman, S. Smeulers, J.R Wisniewski & J. Wisniewski (Eds.) Proceedings 1st International Nitrogen Conference, Noordwijkerhout, pp. 479–485.

Habekotté B. & Hilhorst, G. J., 1998. Yield and quality of mais in relation to P-status of the soil at 'De Marke'. In: Habekotté, B., H.F.M. Aarts, W.J. Corré, G.J. Hilhorst, H. Van Keulen, J.J. Schröder, O.F. Schoumans & F.C Van Der Schans (Eds.) Sustainable dairy farming and phosphorus management (in Dutch). Report 92, Institute for Agrobiological and Soil Fertility Research (AB-DLO), Wageningen, pp. 65–85.

Hassink, J., 1994. Effects of soil texture and grassland management on soil organic C and N and rates of C and N mineralization. *Soil Biology & Biochemistry* 26: 1221–1231.

Jarvis, S.C., R.J. Wilkins & B.F. Pain, 1996. Opportunities for reducing the environmental impact of dairy farming management: a system approach. *Grass and Forage Science* 51: 21–31.

Leneman, H., D.A. Oudendag, K. W. Van Der Hoek & P. H. M. Janssen, 1998. Focus on emission factors: a sensitivity analysis of ammonia emission modelling in the Netherlands, In: K. W. Van Der Hoek, J. W. Erisman, S. Smeulers, J. R. Wisniewski & J. Wisniewski (Eds.), Proceedings 1st International Nitrogen Conference, Noordwijkerhout, pp. 205–211.

Oenema, O. & C.W.J. Roest, 1998. Nitrogen and phosphorus losses from agriculture into surface waters; the effects of policies and measures in the Netherlands. *Water Science and Technology* 37: 19–30.

Paul, J.W., N.E. Dinn , T. Kannangara & L.J. Fisher, 1998. Protein content in dairy cattle diets affects ammonia losses and fertilizer nitrogen value. *Journal of Environmental Quality* 27: 528–534.

Van Den Brandt, H.P. & H.P. Smit,1998. Mineral accounting: the way to combat eutrophication and to achieve the drinking water objective. *Environmental Pollution* 102: 705–709.

Van Der Paauw, F., 1956. Calibration of soil test methods for the determination of phosphate and potash. *Plant and Soil* 8: 105–125.

Van Der Schans, F.C., 1998. P in feed at 'De Marke' (in Dutch). In: Habekotté, B., H.F.M. Aarts, W.J. Corré, G.J. Hilhorst, H. Van Keulen, J.J. Schröder, O.F. Schoumans & F.C Van Der Schans (Eds.), Sustainable dairy farming and phosphorus management. Report 92, Institute for Agrobiological and Soil Fertility Research (AB-DLO), Wageningen, pp. 101–126.

Velthof, G. L. & O. Oenema, 1997. Nitrous oxide emission from dairy farming systems in the Netherlands. *Netherlands Journal of Agricultural Science* 45: 347–360.