



Participatory farm management adaptations to reduce environmental impact on commercial pilot dairy farms in the Netherlands

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ABSTRACT

Regulations in the Netherlands with respect to nutrient use force dairy farmers to improve nutrient management at the whole-farm level. On experimental farm 'De Marke', a coherent set of simple measures at farm level has been implemented, which has resulted in a drastic reduction in input of nutrients without affecting production intensity (milk production; kg milk per ha). To promote adoption of these measures in commercial dairy farming, the project 'Cows & Opportunities' was initiated in which 16 commercial pilot farms participated. Data were collected over a 6-year period (1998–2003). This paper describes and analyses the different farm management strategies adopted on these farms, using two classifications of the farms at the start of the project (the base situation), one based on nitrogen (N) surplus (kg ha^{-1}), the other on production intensity. In both classifications, the farms were split in two equal groups. Changes over time in farm characteristics (farm development) were described through linear regression for each group and the variance among farms within a group was used to test for differences between groups. Under the influence of economic driving forces, the pilot farms, on average, expanded land area and increased their milk quota. However, the most intensive farms could comply with regulations only by reducing production intensity. From 1998 to 2002, average nutrient surpluses on the pilot farms decreased by 33% for N and 53% for phosphorus (P). Important measures were reducing the use of inorganic fertilizer, optimizing the use of home-produced organic manure, reducing grazing time, reducing the number of replacement stock and lowering crude protein content in the ration. Over the years, variation in N surpluses among farms (inter-farm variation) remained almost constant. Differences in farm management strategy could not unequivocally be related to farm typology (high/low N surplus; high/low production intensity). It was concluded that decisions by individual farmers on farm development are not always based on 'rational' arguments, but are co-determined by 'emotional' perceptions.

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1. Introduction

Agriculture has been identified as a major contributor to nutrient losses to the environment [1–4], especially from livestock manure. To identify attractive options for reducing nutrient losses, whole-farming system research is needed [5], as management interventions in one nutrient flow may affect flows elsewhere in the system ('*ceteris non-paribus*'). This holds especially for mixed farming systems, such as intensively managed dairy farming systems in Western Europe. The major constraints on long-term sustainability of these systems are economic profitability and environmental sustainability, resulting from societal demands. Cornelissen [6]

identified these 'two faces of sustainability', based on Koestler's metaphor of the Janus-faced Holon, as a common ground for sustainable development.

Pressure is increasing on the dairy industry in Western Europe, exposed to a globalizing market, in which the developments in the price of milk are insufficient to keep pace with the increasing costs of production, associated with rising energy costs. To maintain income, farmers respond by increasing milk quota and to some extent also land area, however with the net result of intensification, i.e., a higher milk production per ha and per man-hour, to reduce land and labour costs per unit milk production. In the Netherlands, the average price of agricultural land is 40 k€/ha. Evidently, such high land prices force farmers to intensify farming practices. This process of intensification is accompanied by increasing milk production per cow and off-farm rearing of young stock to specialize in milking cows.

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In the Netherlands, legislation to reduce losses of nutrients from manure has been implemented since 1984. In 1998, the MINeral Accounting System (MINAS) as a balance approach was introduced as the central instrument for restricting emission of nutrients to the environment¹ [9]. To comply with the tightening environmental standards, farmers adapted management through reducing fertilization, restricting grazing time, exporting manure, covering slurry storage, applying slurry through injection into the soil, reducing young stock and restricting feed protein content. To explore possible options for dairy farming systems on leaching-sensitive sandy soils, to increase nutrient use efficiency and reduce nutrient losses, the method of prototyping, a combination of system modelling and system implementation, was applied on the experimental farm 'De Marke' [10]. Performance of the 'De Marke' system has shown that by implementing a coherent set of simple measures at farm level, nutrient inputs to the farm can be drastically reduced without affecting production intensity (kg milk per ha) [11,12]. To promote adoption of this approach in commercial dairy farming, the project 'Cows & Opportunities' was initiated in 1999. The project builds on experiences at 'De Marke' and can be considered an extension of the prototyping method. It is characterized by agreements with the farmers on measurable targets and intensive coaching with frequent interaction between researchers and farmers [13].

The commercial pilot farms accepted the commitment to aim for immediate compliance with national environmental standards (permitted nitrogen (N) and phosphorus (P) surpluses per ha land area), which, according to legislation, is compulsory for other commercial farmers in 3–5 years. Maximum permitted nutrient surpluses are farm-specific, depending on soil type, hydrology, cropping pattern and production intensity. Pilot farmers were supported during a 6-year period (1998–2003) in identifying the farming system that best matched their specific conditions and their aspirations. The objective of this paper is to describe and analyse adaptations in farm management on the pilot farms, as governed by farmers' aspirations and societal demands. We want to illustrate that the implemented measures to comply with regulations depend on production intensity and N surplus at the start of the project, taking into account the farmers' aspirations (e.g., farm income, herd or crop management). Moreover, we want to show that intensive coaching and frequent interaction between researchers and farmers on commercial pilot farms results in a higher adoption rate of modified management, resulting in promising future dairy farming systems.

2. Materials and methods

2.1. Research methodology

The most important target of the pilot farms was reducing the nutrient surpluses in a cost-effective way. An intensive annual 'analysis–modelling–planning–implementation–monitoring–analysis' cycle was followed, involving active participation of farmers, researchers and extension officers. At the start, each farm was analysed in detail to quantify the gap between its current situation and the targets, as a basis for identification of measures to bridge that gap [13]. The expected economic and environmental effects of these measures were simulated with the whole-farm dairy model DairyWise [14]. Based on these analyses, farm-specific plans were designed and discussed with the various stakeholders, i.e., farmers,

¹ In 2003, the European Court of Justice rejected the use of MINAS as an instrument to comply with the EU Nitrate Directive [7]. In response to this court order, in 2004, the Netherlands introduced permitted N rates (so-called 'application standards') for all crops [8]. The data in this paper cover the period 1998–2003, i.e., before the change in regulations.

researchers, and extension agents involved, and the farm strategy (combination of measures) that resulted in the most complete realization of the project objectives and best matched the farmers' aspirations, was implemented.

For comparison of the representativeness of the pilot farms, a 'national average' was calculated, based on specialized dairy farms (land area >15 ha, at least 80% grassland and fodder crops, >30 milking cows; $n = 217$), derived from the Dutch Farm Accountancy Data Network (FADN) [15].

2.2. Data collection and monitoring

Data from 16 specialized pilot dairy farms were collected over a 6-year period (1998–2003). For details on farm selection and farm characteristics see Oenema et al. [13]. At the start of the project, data for the year 1998, representing the original situation, were derived from farm records and interviews with the farmers. In the course of the project, frequency of collection of the different data varied from monthly to annually. Farmers recorded most basic data, either electronically or on paper. From these primary data, internal and external nutrient flows were calculated. The calculation methods and the sources are summarized in Table 1. Mass flows entering (import) and leaving (export) the farm were derived from farm accounts. Nutrient flows in imported and exported animals were estimated from the number of animals per category (cow, calf and heifer), assuming category-specific nutrient contents [16]. The nutrient composition of imported feeds (concentrates, roughage) was obtained from feed analysis reports and suppliers. N output in milk was quantified by frequent monitoring protein contents (mg l^{-1}) and milk production (l) by the milk processor. Field-level data on inorganic fertilizer and organic manure management, crop yields and grazing regimes were recorded daily in a computerized fertilizer recommendation programme. Dry matter yields were estimated by the farmer for each cut (mowing/grazing), using tools like a tempex disc [22]. Two to four times a year, a well-mixed sample was taken from the slurry pits and a sample from each silage heap, in which nutrient contents were determined according to standardized laboratory methods. Diet compositions were derived by monitoring the feed supply through weighing each feed lot during one week each month. During the monitoring weeks, the different feed components were sampled and analysed for nutrient contents.

Weather conditions were more or less similar for all years, except for the year 2003, when a long dry period in summer caused lower yields, especially for grassland.

2.3. Data analysis

For analysis of the dairy farming system, four major components were distinguished, i.e., herd, manure, soil and crop [11,23,24]. Nutrients cycle through these components, i.e., output from one component is input into another, but losses are incurred in these transfers. The nutrient balance of a component, i.e., the difference between inputs and outputs, characterizes the (in)efficiency in management of a particular nutrient in a particular part of the farm, revealing the weakest and strongest parts of the farming system. The specific type of nutrient balance selected depends on the purpose of the analysis (e.g., [24–27]). We distinguished two levels in the nutrient balances: whole-farm level and component level (Fig. 1). Nutrient balances at farm level (farm balance) were based on nutrients in all products that enter and leave the farm (inputs and outputs; Table 1). Within the farm, four component balances were distinguished, also taking into account the internal flows, and thus providing more specific information for locating the nutrient losses within each specific dairy farming system. A surplus,

Table 1

Classification, source and calculation method (see text for more explanation) of nutrient flows in a dairy farm system (I = input; O = output; S = surplus), for the whole farm and the components herd and soil. S is defined as the (positive) difference between inputs and outputs of a (sub-)system.

Nutrient flow	Farm balance	Component balance		Source and calculation method
		Herd	Soil	
Imported animals	I	I		Farm accounts + N content per animal category [16]
Imported concentrates	I	I		Farm accounts
Imported roughage	I	I		Farm accounts
Imported fertilizer	I		I	Farm accounts
Imported manure	I		I	Farm accounts
Biological N fixation	I		I	Estimated % clover in grassland × total yield (ton dry matter) × 45 [17]
Atmospheric deposition	I		I	Literature, region-specific [18]
Intake from crops on farm		I		Gross production of crops on farm – field, conservation and feeding losses ± changes in stock
Intake during grazing		I		Balance entry of the herd balance
Net field, grazing, conservation and feeding losses			I	6% for harvesting; 10% conservation and feeding (only N); 10–20% grazing, depending on regime (restricted, unrestricted) [19]
Manure to soil ^a			I	Applied organic manure ^b + excreta during grazing ^c
Gross production of crops on farm			O	Harvested crop ^b + field and conservation losses
Gross grass production during grazing			O	Intake during grazing + grazing losses
Exported animals and milk	O	O		Farm accounts
Exported roughage	O			Farm accounts
Exported manure	O			Farm accounts
Gross production of manure		S		Manure to soil + ammonia losses from stable, storage, grazing and spreading + exported manure – imported manure + changes in stock
NH ₃ losses stable and storage	S			Farm-specific model calculation [20]
NH ₃ losses grazing and spreading	S			Farm-specific model calculation [20]
Accumulation of nutrients in the soil	S		S	Not determined, part of 'surplus'
Denitrification	S		S	Not determined, part of 'surplus'
Leaching and run-off	S		S	Annually measured on each farm [21], in this study part of 'surplus'

^a Excluding ammonia losses from stable, storage, grazing and spreading.

^b Field registration + representative samples (see text for explanation).

^c Derived from the manure production in stable and the length of the grazing season: hours grazing/total hours × manure in stable (including ammonia losses in stable and during storage).

i.e., a positive difference between inputs and outputs, corrected for changes in stock, indicates nutrient losses:

$$\text{Surplus} = \text{maximum}(0, \text{Input} - \text{Output} + \text{Changes in stock}) \quad (1)$$

In order to identify whether and if so, where exactly in the system losses can be reduced, the efficiency of the whole system and the efficiencies of the underlying components must be assessed, for which nutrient use efficiency (NutUE) is used, defined as the ratio output/input (O/I).

In this paper we focus on the farm balance and on the balances for the two most important components (herd and soil) of a dairy farm (Fig. 1; Table 1). Soil balance in this study is defined as the difference in nutrient flows entering and leaving through the soil surface. Crop and manure balances can be used to identify field (grazing and harvesting), conservation and feeding losses and losses of ammonia (stable, storage, grazing and spreading), respectively, but these are not being treated in this paper. First,

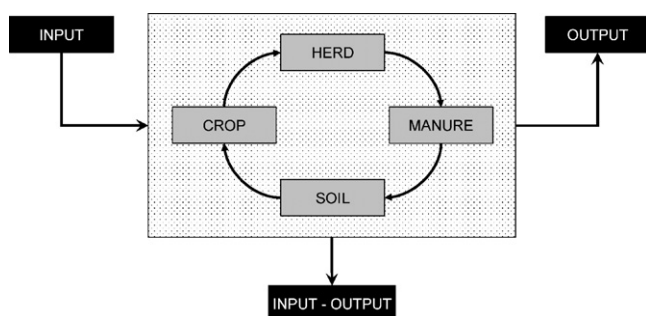


Fig. 1. Main nutrient flows on a dairy farm.

these balances do not provide additional information in analysing the farming systems, and second, in calculating these balances, assumptions would have to be made for the magnitude of losses that were not monitored.

The most important nutrient flows for the farm as a whole were analysed in an analysis of variance with farms and years as treatment factors. Whether differences among farms could be explained by soil type was tested using the REML algorithm (method of residual maximum likelihood) [28].

Strategies to reduce nutrient losses are farm-specific, depending on technical and financial conditions and on the farmer's aspirations. Implementation of strategies leads to changes in various farm characteristics; the combined effect of these changes on the farming system is referred to as farm development. The dynamics of a number of these characteristics have been analysed. To analyse differences in farm development, two classifications were applied to the 16 commercial pilot farms, one on the basis of the magnitude of N surplus (kg ha^{-1}) in the original situation, the other on the basis of production intensity (kg milk per ha) in the original situation. In both classifications, the farms were split in two equal groups ('low' and 'high'; $n = 8$).

We assumed that development of farm characteristics (C) (see next section) can be described by linear relations that might be different for the two groups. Hence, a linear regression was performed and the variance among farms within a group was used to test for differences between groups. The regression model used was:

$$C_i = \beta_0 + \beta_1 * y + \beta_2 * \text{group}_i + \beta_3 * y * \text{group}_i \quad (2)$$

where $i = 1, 2$ for group 'low' and 'high', respectively, $\text{group}_1 = 0$, $\text{group}_2 = 1$. y is the number of years since implementation of the strategies, and β_0 , β_1 , β_2 and β_3 are the parameters to be esti-

mated. β_0 represents the starting value for group 1 (1998), β_1 the 'development rate' per year of group 1, β_2 the difference in intercept between the two groups and β_3 the difference in development rate between the two groups.

3. Results

3.1. Farm characteristics of the commercial pilot farms at the start

To characterize the commercial pilot farms at the start of the project (1998), four groups of characteristics were selected, describing the main aspects of the dairy farming system: farm size, overall N management, herd and feed management and crop management, including inorganic fertilizer regime (Table 2). Farm size was characterized by milk quota (kg) and land area (ha). Average milk quota (kg) of the pilot farms was similar to the 'national average' in 1998, but average land area was smaller. Production intensity of the pilot farms was on average higher (by around 1800 kg milk per ha) than the 'national average'. N surplus (kg ha⁻¹) on the pilot farms was lower than the 'national average', whereas Nitrogen Use Efficiency (NUE) at farm level was higher. Average milk production per cow on the pilot farms was higher than the 'national average', but with substantial variation. 'National average' inorganic fertilizer doses were higher than those on the pilot farms. Most striking was the difference in allocation of organic manure to

crops: on 'national average' much more was used on maize land than on grassland, in contrast to what was the case on the pilot farms.

3.2. Nutrient flows

Nutrient surpluses were not significantly different among soil types (data not shown), although N surpluses for the farms on clay were on average high compared with those for the farms on sand, peat and loess.

Average N surplus of the farms (Fig. 2) decreased significantly ($p < 0.001$) between 1998 and 2002, i.e., from 272 to 179 kg ha⁻¹, followed, in 2003, by an increase to 206 kg ha⁻¹. N surplus in any given year varied strongly among farms (e.g., in 1998 from 169 to 424 kg ha⁻¹), as a result of differences in management and management skills, and spatial variability. Inter-annual variability in N surplus for individual farms was also very high (largest difference between 217 and 424 kg ha⁻¹), due to differences in management and weather conditions from year to year. Inorganic fertilizer input significantly declined over time (from 178 to 98 kg ha⁻¹ on average). The correlation between N surplus and inorganic fertilizer input was high ($r^2 = 0.76$), indicating that the decrease in inorganic fertilizer input contributed most to the reduction in N surplus. On the other hand, feed input was also strongly correlated with N surplus ($r^2 = 0.61$). In all years, the highest feed input was recorded

Table 2
Farm characteristics of commercial pilot farms (including standard deviation (Sd)) and the 'national average' farm (see text for explanation) in 1998, at the start of the project 'Cows and Opportunities'.

	'National average'	Cows & Opportunities	
		Average	Sd
<i>Farm size</i>			
Quota (kg milk)	574,006	570,339	136,213
Farm area (ha)	44	40	12
Production intensity (kg milk per ha)	13,046	14,901	3,883
<i>Overall nitrogen management</i>			
N surplus farm (kg ha ⁻¹)	381	272	63
NUE-farm (%)	17	26	5
NUE-herd (%)	19	22	3
NUE-soil (%)	51	74	11
<i>Herd & feed management</i>			
Number of cows	76	74	20
Number of young stock (per 10 cows)	8.3	8.0	2.1
Milk per cow (kg yr ⁻¹)	7580	8098	985
Fat content milk (%)	n.a. ^a	4.37	0.18
Protein content milk (%)	n.a.	3.48	0.08
Urea content milk (mg per kg milk)	n.a.	23	4.7
Grazing time cows (h) ^b	2458	1768	691
Concentrates (kg per 100 kg FPCM ^c)	28	25	4
Crude protein in winter ration (%)	n.a.	15.8	0.9
Crude protein in summer ration (%)	n.a.	18.1	1.8
<i>Crop & fertilizer management</i>			
Grassland area (%)	84	75	15
<i>N fertilization grassland</i>			
- Inorganic fertilizer (kg ha ⁻¹)	283	221	74
- Organic manure (kg ha ⁻¹)	196	221	60
<i>N fertilization maize land</i>			
- Inorganic fertilizer (kg ha ⁻¹)	55	50	52
- Organic manure (kg ha ⁻¹)	279	178	100
<i>P fertilization grassland</i>			
- Inorganic fertilizer (kg ha ⁻¹)	14	12	14
- Organic manure (kg ha ⁻¹)	31	33	9
<i>P fertilization maize land</i>			
- Inorganic fertilizer (kg ha ⁻¹)	15	14	15
- Organic manure (kg ha ⁻¹)	42	26	14

^a Not available.

^b Number of grazing days × hours per day.

^c Fat-and-protein corrected milk.

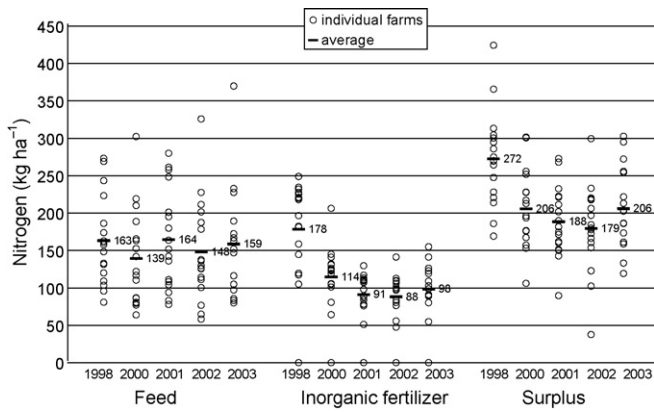


Fig. 2. Imported nitrogen in feed and inorganic fertilizer, and farm surplus for the commercial pilot farms in 1998 (original situation), 2000, 2001, 2002 and 2003.

on the farm with the highest production intensity (milk production between 20,000 and 25,000 kg ha⁻¹). Export of animal manure decreased (from 23 to 15 kg N ha⁻¹; data not shown), suggesting that farmers increasingly used farm-produced animal manure to reduce the cost of expensive inorganic fertilizer.

Average P surplus of the farms significantly decreased ($p < 0.005$) from 19 kg ha⁻¹ in 1998 to 8 kg ha⁻¹ in 2000, after which it stabilized until 2002. Similarly to N, P surplus in 2003 increased to 12 kg ha⁻¹ (Fig. 3). Comparable with N, the major contribution to the reduction in surplus came from a decrease in inorganic fertilizer input: P surplus and inorganic-P fertilizer dose were more closely correlated than P surplus and feed input ($r^2 = 0.74$ and 0.36, respectively). On most farms, less than 10 kg ha⁻¹ inorganic-P fertilizer was applied, but on individual farms the dose exceeded 20 kg ha⁻¹, from 2000 onwards on a single farm, located on strongly P-fixing clay soil.

No statistically significant difference was found among years in average N input into the herd in feed (concentrates, roughage and grass) (Fig. 4). The variation in annual N input among farms was very high (e.g., from 291 to 586 kg ha⁻¹ in 1998), whereas inter-annual variation for individual farms was less (largest difference from 294 to 511 kg ha⁻¹). P input remained constant at around 60 kg ha⁻¹, but with a very high variation among farms within any year. Variation in nutrient output in milk and animals was much smaller than in input, and output remained constant between 1998 and 2003.

Average total nutrient input into the soil (Fig. 5) significantly decreased between 1998 and 2003: for N from 510 to 410 kg ha⁻¹ ($p < 0.005$) and for P from 54 to 44 kg ha⁻¹ ($p < 0.01$). In particular, inputs in inorganic fertilizer (Figs. 2 and 3) and in organic manure

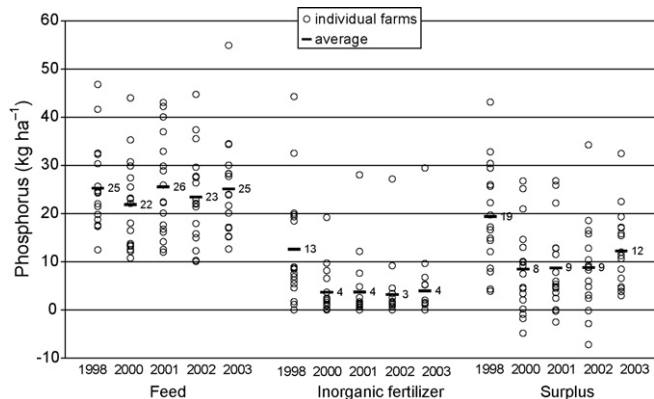


Fig. 3. Imported phosphorus in feed and inorganic fertilizer, and farm surplus for the commercial pilot farms in 1998 (original situation), 2000, 2001, 2002 and 2003.

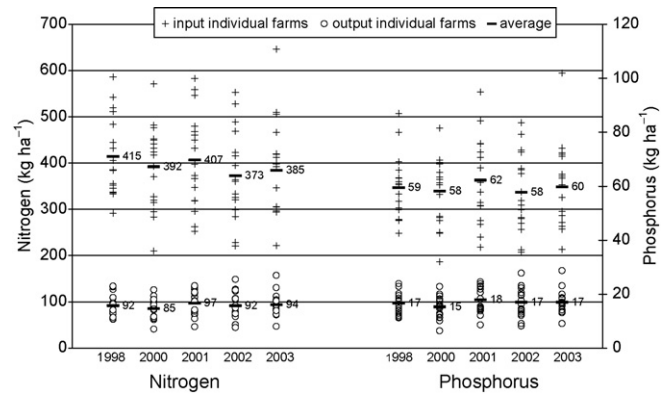


Fig. 4. Nitrogen and phosphorus inputs and outputs of the herd for the commercial pilot farms in 1998 (original situation), 2000, 2001, 2002 and 2003.

during grazing decreased; the latter as a result of reduced grazing time (see next section). Total crop nutrients (i.e., nutrient content before harvesting or grazing; output from the soil balance) also decreased significantly ($p < 0.05$). Compared with the 309 kg N ha⁻¹ in 1998, total crop-N in 2003 was 20% lower (250 kg ha⁻¹), mainly because of the dry summer. In 2002, N yields were 14% higher than in 2003, at the same input level. Total crop-P decreased by 11% from 1998 to 2003, but in intermediate years output was higher.

In 2003, nutrient yield on one farm, especially for N, was exceptionally high. Most likely, for this farm on peat soil, the above-average temperatures in that year have resulted in high mineralization rates and thus high soil-N availability.

3.3. Farm development

Development of N surplus (kg ha⁻¹) strongly varied among farms (Fig. 6). Moreover, the rate of development showed inter-annual variation. The range in N surpluses among farms remained almost constant over time. In Table 3, development of farm characteristics between 1998 and 2002 is presented for the two groups of farms, classified on the basis of N surplus level in 1998 ('low' and 'high'). The year 2003 was excluded from the linear regression because it was very dry, with consequently lower crop yields (Fig. 5) and higher N surpluses (Figs. 2 and 6).

At the start, group 'high' had a higher milk quota and smaller farm area than group 'low'. In both groups, milk quota, land area and production intensity increased over time. The difference in average N surplus between the groups at the start was 87 kg ha⁻¹, and for both groups the surplus decreased. All NUES (-farm, -herd and -soil) from group 'low' in 1998 were higher than those from group 'high',

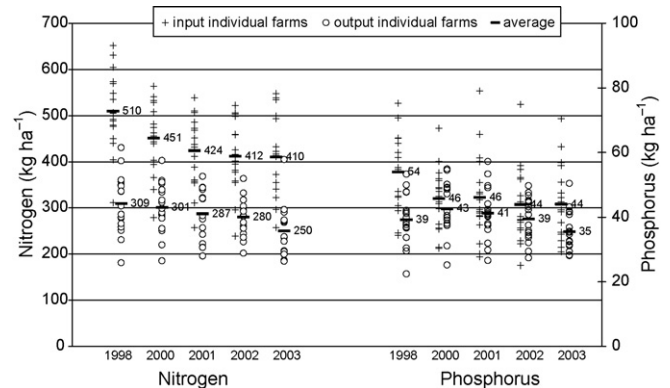


Fig. 5. Nitrogen and phosphorus inputs and outputs of the soil for the commercial pilot farms in 1998 (original situation), 2000, 2001, 2002 and 2003.

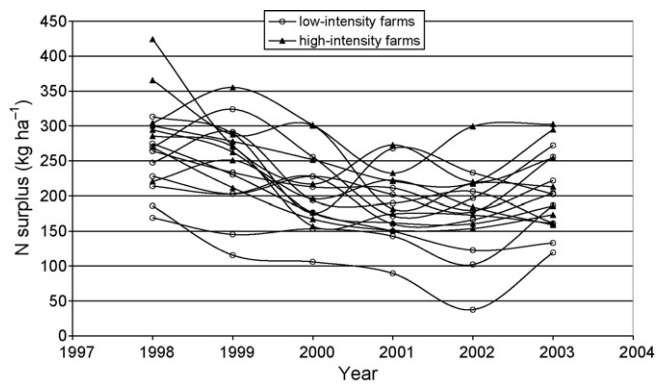


Fig. 6. Changes over the period 1997–2004 in N surplus on the commercial pilot farms. Each graph represents an individual farm. Farms classified on the basis of their intensity in 1998.

and they all increased statistically significantly between 1998 and 2002 for farm and soil. Most pronounced developments in herd and feeding regime characteristics were a decrease in number of young stock and in grazing time, and an increase in fat content in

Table 3

Farm development of two groups of commercial pilot farms, classified ($n=8$) on the basis of N surplus level at the start in 1998 ('low' and 'high'). For each characteristic, the absolute starting value in 1998 is given (β_0 and $\beta_0 + \beta_2$) and the average development rate per year between 1998 and 2002 (β_1 and $\beta_1 + \beta_3$) (see Eq. (2) for explanation of symbols).

	N surplus						
	Starting value in 1998		Development rate (y^{-1})		Statistical significance ^c		
	Low (β_0)	High ($\beta_0 + \beta_2$)	Low (β_1)	High ($\beta_1 + \beta_3$)	β_1	β_2	β_3
<i>Farm size</i>							
Quota (Mg milk)	533	583	26	40	*		
Farm area (ha)	40	36	1.6	2.5			
Production intensity (Mg milk ha^{-1})	13.7	16.4	0.2	0.1			**
<i>Overall nitrogen management</i>							
N surplus farm ($kg\ ha^{-1}$)	225	313	-18	-30	***	***	
NUE farm (%)	27.5	24.8	2.6	2.4	***		
NUE herd (%)	22.7	21.5	0.4	0.7			
NUE soil (%)	64	59	2.4	2.1	**		
<i>Herd & feed management</i>							
No. of cows	71.7	70.0	2.7	6.1			
No. of young stock (per 10 cows)	7.7	9.3	-0.2	-0.3	*		***
Milk per cow ($kg\ yr^{-1}$)	7978	8108	11	-96			
Fat content milk (%)	4.38	4.33	0.04	0.03	**		
Protein content milk (%)	3.49	3.51	-0.02	0.0			
Urea content milk (mg per kg milk)	20.4	24.3	0.07	-0.53			*
Grazing time cows (h) ^a	1700	1926	-154	-136	*		
Concentrates ($kg\ per\ 100\ kg\ FPCM$) ^b	22.3	26.6	0.6	-1.0			*
Crude protein in winter ration (%)	15.9	16.8	-0.03	-0.3			
Crude protein in summer ration (%)	17.8	18.2	-0.3	-0.3			
<i>Crop & fertilizer management</i>							
Grassland area (%)	67	77	1.7	-1.5			*
<i>N fertilization grassland</i>							
Inorganic fertilizer ($kg\ ha^{-1}$)	202	262	-27	-39	***	**	
Organic manure ($kg\ ha^{-1}$)	230	235	3	13			
<i>N fertilization maize land</i>							
Inorganic fertilizer ($kg\ ha^{-1}$)	35	60	-1.3	-1.9			
Organic manure ($kg\ ha^{-1}$)	196	251	-15	-19			
<i>P fertilization grassland</i>							
Inorganic fertilizer ($kg\ ha^{-1}$)	4	17	-1	-3		***	*
Organic manure ($kg\ ha^{-1}$)	36	35	1	2			
<i>P fertilization maize land</i>							
Inorganic fertilizer ($kg\ ha^{-1}$)	11	18	-3	-3			
Organic manure ($kg\ ha^{-1}$)	31	37	-2	-2			

^a No. of grazing days \times hours per day.

^b Fat-and-protein corrected milk.

^c * $p < 0.10$; ** $p < 0.05$; *** $p < 0.001$.

milk. Between the groups, these developments were not statistically different (β_3). At the start, the proportion grassland on farms in group 'low' was 10% lower than that in group 'high', but the difference declined over time. N en P inorganic fertilizer doses in 1998 on grassland and maize land in group 'high' were higher than in group 'low', and decreased in both groups. At the start, group 'high' applied absolutely and relatively more organic manure to maize land, and both groups shifted manure application from maize land to grassland (group 'high' to a larger extent than group 'low').

Table 4 presents the development of farm characteristics for the two groups of farms, classified on the basis of production intensity in 1998 ('low' and 'high'). The difference in intensity between the groups in 1998 was $4.3\ Mg\ ha^{-1}$. In both groups, milk quota and land area increased, but in the high-intensity group priority was given to land area, resulting in a decrease in intensity. At the start, N surplus on the low-intensity farms was lower ($60\ kg\ ha^{-1}$), as was NUE at farm level (24.9% versus 27.4%). This is in contrast to the groups of farms in Table 3, where a lower N surplus was associated with a higher NUE at farm level. The increase in NUE-farm and NUE-soil was stronger in the low-intensity group than in the high-intensity group. The difference between the groups was most pronounced for NUE-soil (3.1% versus 1.3%). The rate of development of the farm characteristics related to feeding regime (urea content in milk and

Table 4

Farm development of two groups of commercial pilot farms, classified ($n=8$) on the basis of intensity (milk production per ha) at the start in 1998 ('low' and 'high'). For each characteristic the absolute starting value in 1998 is given (β_0 and $\beta_0 + \beta_2$) and the average development rate per year between 1998 and 2002 (β_1 and $\beta_1 + \beta_3$) (see Eq. (2) for explanation of symbols).

	Production intensity		Development rate (y^{-1})		Statistical significance ^c		
	Starting value in 1998				β_1	β_2	β_3
	Low (β_0)	High ($\beta_0 + \beta_2$)	Low (β_1)	High ($\beta_1 + \beta_3$)			
<i>Farm size</i>							
Quota (Mg milk)	509	606	46	20	**	*	
Farm area (ha)	42.0	35	1.5	2.6			
Production intensity (Mg milk ha^{-1})	12.4	17.7	0.6	-0.3	*	***	**
<i>Overall nitrogen management</i>							
N surplus farm (kg ha^{-1})	238	299	-19	-28	**	**	
NUE farm (%)	24.9	27.4	3.1	1.9	***		
NUE herd (%)	21.8	22.3	0.5	0.6	*		
NUE soil (%)	61	62	3.1	1.3	***		
<i>Herd & feed management</i>							
No. of cows	70.6	71	4.2	3.7	*		
No. of young stock (per 10 cows)	7.9	9.1	-0.1	-0.4		*	
Milk per cow (kg yr^{-1})	8054	8029	-7	-77			
Fat content milk (%)	4.36	4.34	0.04	0.03	*		
Protein content milk (%)	3.47	3.52	-0.01	0.0			
Urea content milk (mg per kg milk)	22.7	22.1	-0.4	0.0			
Grazing time cows (h) ^a	1676	1949	-146	-181			
Concentrates (kg per 100 kg FPCM ^b)	22.3	26.6	0.8	-1.3			**
Crude protein in winter ration (%)	16.6	16.1	-0.2	0.0			
Crude protein in summer ration (%)	19.1	17.1	-0.6	-0.2	**	*	
<i>Crop & fertilizer management</i>							
Grassland area (%)	72	73	1.2	-1.0			
N fertilization grassland							
Inorganic fertilizer (kg ha^{-1})	213	252	-29	-36	***	*	
Organic manure (kg ha^{-1})	225	240	7	9			
N fertilization maize land							
Inorganic fertilizer (kg ha^{-1})	49	47	-1	-2			
Organic manure (kg ha^{-1})	184	260	-16	-19		*	
P fertilization grassland							
Inorganic fertilizer (kg ha^{-1})	10	12	-3	-2	**		
Organic manure (kg ha^{-1})	35	35	1	2			
P fertilization maize land							
Inorganic fertilizer (kg ha^{-1})	19	11	-5	-1	**		*
Organic manure (kg ha^{-1})	29	38	-2	-2			

^a No. of grazing days \times hours per day.

^b Fat-and-protein corrected milk.

^c * $p < 0.10$; ** $p < 0.05$; *** $p < 0.001$.

crude protein (CP) percentage in the ration in summer) was higher in the low-intensity group than in the high-intensity group. The patterns of N and P fertilization on grassland and maize land at the start, as well as their development, were generally the same as in Table 3, except for the inorganic-N fertilizer dose on maize land at the start: no difference between the groups classified on the basis of production intensity and almost double the dose in the group 'high surplus' compared with the group 'low surplus'.

3.4. Relation between intensity and nitrogen surplus

The characteristics production intensity and N surplus were used as criteria to analyse differences in farm management (Fig. 7). In a multiple linear regression model with year, production intensity and their interaction, 48% of the variance of N surplus was accounted for. For each year the p -value of the slope was less than 0.014, except for 1998 ($p = 0.069$). In all years, the relation between these characteristics has more or less the same slope: for each Mg increase in milk yield per ha, N surplus increased by 6–13 kg ha^{-1} . Progress at individual farms in the course of the project was characterized by a lower surplus at a given production intensity. At a production intensity of 15,000 kg ha^{-1} mean N surplus decreased

from 273 kg ha^{-1} in 1998 to 179 kg ha^{-1} in 2002. Similar relations were found on progressive Flemish dairy farms [29].

The characteristics for the year 2003 were similar to those in 2000 as a consequence of the dry summer and the associated lower yields of grassland. The lower slope for 1998 is associated with the

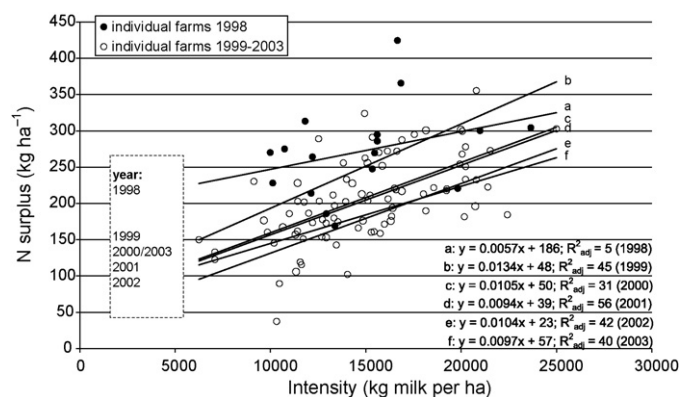


Fig. 7. Relation between intensity and N surplus of the commercial pilot farms in the years between 1998 and 2003.

relatively low N surpluses realized by the most intensive farms at the start.

4. Discussion and conclusions

Developments on farms are pre-dominantly governed by technical and financial conditions and farmers' aims and aspirations, but these are modified by regulations based on societal demands. From the start in 1998 until 2002, average nutrient surpluses on the commercial pilot farms in the project 'Cows & Opportunities' decreased by 33% for N and 53% for P. On the 'national average' farm [15], nutrient surpluses decreased in the same period almost similarly for N (29%), but less for P (28%). However, on the commercial pilot farms, NutUE in 2002 was 34% for N and 67% for P compared with 23% and 49%, respectively, on the 'national average' farm. Production intensity on the 'national average' farm remained lower than on the commercial pilot farms. Intensive coaching and very frequent interaction among researchers, extension agents and farmers resulted in adoption and implementation of nutrient-efficient management in practice (see Section 4.1). Similar results were found on farms with access to advice and information systems in other developed countries [30] and in developing countries [31]. Aarts [32] reported for the same set of pilot farms that adoption of nutrient-efficient farm management, triggered by its reduced environmental impact, was stimulated by the associated increase in farmers' income (on average €3000 over 5 years), due to reductions in purchases of feeds and inorganic fertilizer. Under the influence of economic driving forces, the pilot farms on average expanded land area and increased their milk quota, resulting in a limited increase in production intensity. This strategy is in agreement with the results of Ondersteijn et al. [33], who concluded that farms tend to grow in size and in production intensity to survive in the current harsh economic environment. Higher production intensity results in higher N surpluses (Fig. 7), which is in contradiction with the main target of the pilot farms: reducing nutrient losses. The solution to reconciling these conflicting objectives and develop more nutrient-efficient management is found elsewhere in the dairy farming system.

4.1. Implemented measures

Effective strategies to reduce nutrient losses are based on optimizing internal nutrient cycling in subsystems, so that external inputs of nutrients can be reduced. That was the main motive underlying implementation of MINAS (specifying permitted nutrient surpluses) as a policy instrument. The most effective measure is reducing the use of inorganic fertilizer (Figs. 2 and 3) through increased use of farm-produced animal manure (less is exported) and higher utilization efficiency through improved allocation to crops (from maize to grass; Tables 3 and 4) and timing of application. As dry matter yields hardly decreased [34], the lower N input levels especially reduced the N content of home-produced feed (Fig. 5), but not its energy content. So lower N yields did not increase the need for purchased feed (Figs. 2 and 3).

Another important measure is reducing grazing time (Tables 3 and 4). The disadvantage of grazing is that the composition of feed rations is difficult to manage. Grass intake, as well as its quality, is variable (weather conditions), and both are difficult to estimate quantitatively. Under grazing, field losses are higher than under harvesting as silage. However, before grass silage is ingested, losses occur during conservation and feeding. The spatial distribution pattern of manure during grazing is so unfavourable that grass hardly profits from its nutrients, and there is a high risk of excessive nitrate leaching [35,36]. Systems with grazing require

a favourable parcelling pattern (size of plots, distance to the farm). On the other hand, grazing systems are less labour-intensive and their costs are lower, as mechanical harvesting is not needed and housing requirements are simpler. Moreover, grazing is preferable from the point of view of animal health and welfare. Also from a societal point of view there is a demand for grazing systems.

Another measure is to reduce the relative number of young stock, as they present a highly inefficient component in the nutrient balance. Each additional heifer (young stock older than 1 year) increases the farm nutrient surpluses by 51 kg N and 7 kg P [37]. Young stock management is important because of selection for replacement. Replacing a milking cow requires an 'investment' in nutrients and energy intake [38]. On the other hand, raising or fattening young stock on other farms is a case of shifting this 'investment' elsewhere.

Changing fertilization management (reduced use of mineral fertilizer, optimizing use of animal manure to crops) and grazing regime influenced the composition of home-produced feed. Crude protein (CP) content of the rations hardly decreased. At the start, average CP contents of the ration in winter (15.8%) were lower than 'national average', so further reduction has low priority. Theoretically, a CP content of 13.5% would be sufficient [39], but that requires highly skilled management to provide a balanced dietary energy/protein ratio to sustain milk production. Most progress has been made in lowering the CP content in the ration in summer, by shortening grazing time and supplementary stall-feeding to balance the ingested protein/energy ratio. The lower CP content of the ration did not affect milk production per cow, nor fat and protein content of the milk (Tables 3 and 4).

4.2. Does strategy depend on intensity or nitrogen surplus?

This study contributes to closing the information gap on the causes underlying the variation in system performance among specialized dairy farms and years, by systematically examining whether differences can be explained by different management practices. The inter-farm variation in N surplus remained constant over time (Fig. 6). To explain differences in farm development, in this study, farms were classified on the basis of production intensity and N surplus in the base situation. Farms characterized by low N surpluses at the start still identified opportunities to reduce nutrient losses (Table 3 and Fig. 6). Explanations might be found in factors such as 'learning period' and 'degree of adaptation' [40,41]. The 'N surplus limit' is farm(-type)-specific, and (co-)determined by agro-ecological conditions (e.g., soil type), but also by professional skills and entrepreneurship. These factors are therefore important in understanding differences in farm development. Decisions of farmers to adapt to changing conditions are not only governed by economic considerations, but also by their social and psychological characteristics [42–44].

As the classifications of farms on the basis of initial production intensity and on the basis of initial N surplus strongly overlap, because both characteristics are strongly correlated (Fig. 7), it is difficult to differentiate between the two groups. For the two classes distinguished on the basis of production intensity in the base situation, the most striking development is the reduction in intensity on the high-intensity farms (Table 4). On these farms, the ceiling has been reached in improvements in agro-ecological and socio-economic performance to comply with regulations, such as permitted nutrient surpluses.

For most characteristics, the average differences between groups declined as the project progressed, suggesting development towards a feasible limit for each characteristic, however, with some notable exceptions. For the farms classified on the basis of N surplus in the base situation, the differences between the two

groups in intensity, NUE-farm and NUE-soil, relative number of young stock and grazing time persisted or even increased. For the farms classified on the basis of initial production intensity, this held for NUE-herd and NUE-soil and manure application rate to maize land. Hence, explanations for differences among farms and groups are only valid for an *average* development of farm characteristics. The inter-farm variation in farm characteristics remains high over time. This variation may be related to differences in production environments (both, agro-ecological and socio-economic) in which the farm(er)s operate [33,45,46]. Further research should therefore focus on identification of the factors underlying these substantial inter-farm differences in nutrient surpluses. This requires analyses of the effects of changes in the whole dairy farming system, i.e., farm-specific analyses based on detailed and accurate data on nutrient balances at the whole-farm level and at herd and soil level, combined with analyses of farm characteristics related to the herd and feeding regimes and crop and fertilizer regimes. The ceiling to production intensity to comply with regulations and societal demands is farm-specific and dependent on the willingness and skills of the farmer. Advice to individual farmers has to be situation-specific, based on the results of the farm-specific analyses, and the dairy farming systems on the commercial pilot farms presented in this paper can be used in guiding the promotion of adoption of improved farm management practices. However, differences in farm management strategy could not unequivocally be related to farm typology (high/low N surplus; high/low intensity). Decisions of individual farmers on farm development are not always based on 'rational' arguments, but are co-determined by 'emotional' perceptions.

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