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Dairy farming systems based on efficient nutrient management

H.F.M. AARTS[1], E.E. BIEWINGA[2] & H. VAN KEULEN[1]

[1] DLO-Centre for Agrobiological Research, P.O. Box 14, NL 6700 AA Wageningen, Netherlands
[2] Centre for Agriculture and Environment, P.O. Box 10015, NL 3505 AA Utrecht, Netherlands

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Abstract

In Dutch dairy farming, dramatic nutrient losses occur, causing serious environmental problems and representing an economic and energy waste. So farming systems have to be developed based on efficient nutrient management. A dairy farm is characterized as a system with soils and crops, forage, cattle and manure as main components. Simple models of nutrient flows in and between components of the farming system were used to design a prototype system for a new experimental farm on sandy soil, that has to meet strict environmental demands. Experimental results of this farm will be used to improve the models and the models will be used again to optimize the prototype system. Initial results of modelling suggest that nutrient losses can be reduced considerably by more accurate management and introduction of rather cheap and simple measures. However, more radical and expensive modifications of the farming system are necessary to meet future standards of the Dutch government for maximum allowable emissions.

Keywords:
dairy farming, forage production, milk production, environmental demands, nutrient flow, nutrient utilization, nitrogen, phosphorus

Introduction

Dairy farming, occupying about 65% of the cultivated area and providing the main income to some 35% of its farmers, is the most important sector of Dutch agriculture. In the past, milk production systems were characterized by careful use of animal manure, limited milk production per hectare and integration of arable and dairy farming (Damen, 1978). Over the last decades, however, these systems were strongly intensified by increased inputs of anorganic fertilizers and purchased feeds. Introduction of the milk quota system in 1984 has resulted in a decrease of about 15% in milk production. At present, average annual milk production on dairy farms is about 11 500 kg ha^{-1}, but considerable differences exist between regions and individual farms, with systems on sandy soils being more intensive than on clay or peat soils.

Intensification has also led to a serious imbalance between inputs of nutrients in

Table 1. Average annual nitrogen, phosphorus and potassium balances of specialized dairy farms on sandy, peat and clay soils in the Netherlands, 1983-1986 (Aarts et al., 1988).

	Sand			Clay			Peat		
	N	P	K	N	P	K	N	P	K
Input (kg ha^{-1})									
– fertilizers	331	15	30	340	19	6	295	12	17
– concentrates	137	25	74	122	21	65	127	23	68
– purchased roughage	44	7	34	28	4	18	33	5	20
– atmospheric deposition	48	1	4	39	1	4	42	1	4
– miscellaneous	8	0	4	9	1	3	37	3	3
total	568	48	146	538	46	96	534	44	112
Output (kg ha^{-1})									
– milk	67	12	19	60	11	17	61	11	17
– sold livestock	14	4	1	11	3	1	11	3	1
– miscellaneous	1	0	0	1	0	0	0	0	1
total	82	16	20	72	14	18	72	14	19
Input - Output (kg ha^{-1})	486	32	126	466	32	78	462	30	93
Output/Input (%)	15	33	14	13	30	19	14	32	17

purchased fertilizers, concentrates, roughage and atmospheric deposition and outputs in milk and meat (Table 1). On Dutch dairy farms, output represents on average about 14% of the input for nitrogen (N), 32% for phosphorus (P) and 17% for potassium (K). The average annual surplus of 32 kg P ha^{-1} mainly accumulates in the soil, but continued accumulation will lead to saturation and leaching. The N surplus (about 470 kg ha^{-1}) contributes to environmental pollution by ammonia volatilization, runoff, leaching and denitrification. Dairy farming appears to be the major source of ammonia volatilization and associated acidification (Heij et al., 1991; Van Breemen et al., 1982). Denitrification would seem harmless to the environment, but in addition to N_2, N_2O is produced, a greenhouse gas that also affects the ozone layer (Bach, 1989), while denitrification in the subsoil may result in groundwater pollution by sulphates and heavy metals. Accumulation of N in soil organic matter is difficult to quantify, because of the large quantities present, but available evidence suggests that it accounts for a negligible part of the N surplus (Janssen, 1984).

Recently, the Dutch government has presented target values for emissions of N into the air and into groundwater and surface water, and for additions of P to the soil in the year 2000. For ammonia volatilization it is set at a reduction of 70% compared to the level in 1980. The nitrate concentration in the water at a depth of 2 m below groundwater level should be below 11.3 mg N l^{-1}. Total P application in anorganic fertilizer and manure should not exceed output in crop products. On P-saturated soils input will be even more restricted, to lower the P content of the soil. Therefore, societal demands on dairy farming systems with respect to N losses and P inputs are to become more stringent, requiring more efficient nutrient utilization. In addition, the health and well-being of men and animals, nature and landscape conservation and the use of energy should be taken into account. Nevertheless, costs of milk production, including reasonable income, should not exceed financial returns.

The ultimate goal of farming systems research is to offer guidelines to farmers to design and develop their farms, taking into account their specific circumstances, such as soil type or farm size, and both short- and long-term objectives. This paper describes a research approach to generate the knowledge required for improved nutrient utilization in an economically optimum way. Integration of dairy farming and nature conservation is discussed elsewhere (Hermans & Vereijken, 1992).

Nutrient flows in dairy farming

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, but nutrient losses also occur. In Figure 1,

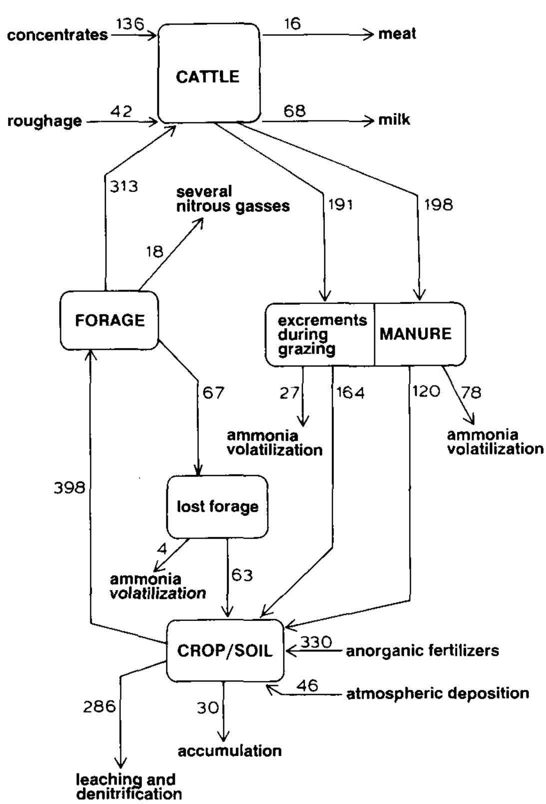

Fig. 1. Main N flows in an average dairy farming system on sandy soil, 1983-1986. Numerical values are kg N ha^{-1} yr^{-1}.

the main N flows on an 'average' farm on sandy soil are quantified. Only a minor part of the N consumed by cattle is converted into milk and meat: about 80% is excreted in urine and faeces. A quarter of this is lost through ammonia volatilization, especially from the excrements produced indoors. The excessive input of N fertilizer and the irregular distribution of excrements during grazing result in 40% loss of N input from the soil, by leaching of nitrate and denitrification (Van der Meer & Van Uum-Van Lohuyzen, 1986). A small part of the N taken up by the crop is lost by volatilization of ammonia and other nitrous gasses during growth and forage conservation. Moreover, some ammonia volatilizes from crop residues, left after grazing and harvesting.

Efficient nutrient management; constraints and perspectives

Single nutrient flows can be influenced by changing management. However, intervening in one step of the cycle may affect nutrient flows elsewhere, i.e. covering a slurry storage reduces direct ammonia emissions, but most of that ammonia will volatilise soon after slurry application, unless a low-emission technique is applied. Injection of slurry into the soil may reduce ammonia emissions considerably, but will lead to increased leaching of nitrate if the input of anorganic N fertilizers is not reduced. Therefore, in a strategy aiming at minimum losses, all the components of the system should be taken into account. Efficient nutrient management implies efficient utilization of nutrients in all stages of the cycle. Hence, conversion of nutrients from manure into forage and from feed into milk and meat should be maximized. Quantifying nutrient balances of the main components of the system can be useful to identify major losses and to find potential limiting or preventive measures.

In research ample attention has been paid to single measures to reduce losses, in the past mainly to economize on fertilizer and feed use, recently mainly to reduce environmental contamination. A considerable amount of information is, therefore, available on the effect of various measures on nutrient losses (e.g. Aarts et al., 1988; Korevaar & Den Boer, 1990). Unfortunately, the effects of most measures have not been tested in combination with other measures. Some measures, like avoiding application of slurry in autumn, or slurry injection, are almost always very effective. The costs and benefits of other measures, both in environmental and economic terms, may depend strongly on specific farm conditions. For instance, growing silage maize to balance the high N content in the summer diet of cows is difficult on peat soils. On these soils, however, a comparable result can be achieved by reducing the N fertilization level of the grass. Growing fodder-beets to partially substitute concentrates is most attractive on farms with a relatively low milk production level per hectare and consequently a surplus roughage. The costs of reducing N losses by restricted grazing strongly depend on farm infrastructure. Therefore, in principle for each group of farms with the same relevant characteristics, or even for each farm, a specific set of consistent measures to meet environmental and economic goals should be developed. Nevertheless, some aspects of optimizing nutrient utilization in the main farm components can be formulated in general terms.

Cattle

At maximum, 43% of the N ingested by lactating cows can be converted into milk and liveweight gain (Van Vuuren & Meijs, 1987), whereas the actual utilization is only 15-25%. The quantity of faeces N of grazing cows is rather constant (Kemp et al., 1979; Van Vuuren & Meijs, 1987). Hence the N surplus in the diet is excreted mainly in urine.

The quality of proteins in the diet also influences the utilization of N. Part of the feed protein is degraded in the rumen. The amino-acids and ammonia produced in the process will be used for microbial growth if enough energy is available, or the surplus will be excreted in urine. As heavily fertilized grass contains a substantial surplus of rumen degradable protein, reducing the protein content by restricted fertilizer application is an important option to improve utilization during grazing (Van Vuuren & Meijs, 1987). Including silage maize, with its low protein content, in the diet has a similar effect (Valk et al., 1990). Where that is not feasible, low protein/high energy concentrates are an alternative.

Utilization of dietary N can also be improved by higher milk production per lactation, because feed requirements per kilogram milk are lower. A higher lifetime milk production means lower replacement rates, requiring less calves to be reared, a rather inefficient form of protein utilization.

Animal manure

To restrict ammonia losses, transport time of excrements produced indoors to closed storage should be minimized by a slightly sloping floor with a central urine-drain and the use of a dung scraper. Preliminary research results suggest a reduction in ammonia volatilization of 50-60% compared to a conventional stable. Storage capacity for slurry, covering at least eight months of slurry production at the farm, should be available to avoid the necessity of slurry application during autumn and winter.

Under the common method of surface spreading of slurry, 25-35% of its N is lost through ammonia volatilization (Van der Meer et al., 1987). Injection of slurry into the soil will prevent ammonia losses almost completely. Also diluting slurry before spreading, or sprinkling during or shortly after application, may reduce losses considerably.

During grazing, faeces and urine are excreted in patches, leading to very high N concentrations locally: in urine patches about 500 and in dung patches about 2 000 kg ha^{-1} (Lantinga et al., 1987). As N in the dung is mainly in stable organic form, only some 13% is lost as ammonia. Nitrogen in urine mainly consists of urea, which easily dissociates in ammonia and carbon dioxide. However, most urine penetrates into the soil, restricting ammonia losses to about 13% (Van der Molen et al., 1989; Vertregt & Rutgers, 1988), while the remainder is transformed into nitrate. Such high amounts of mineral N cannot be taken up by a crop, so a considerable proportion may leach. Restricting grazing to daytime reduces the number of urine and dung patches. If maize is fed indoors, N content in urine will be reduced concurrently, so that, at a given level of fertilizer input, nitrate leaching will be lower (Korevaar &

Den Boer, 1990). A zero-grazing system would reduce nitrate leaching even more, but is detrimental to animal welfare and also labour-intensive.

Soil and crop

Increasing forage production by higher fertilizer application reduces the need for purchased feed, but increases the risk of nitrate leaching. The current Dutch fertilizer recommendation is based only on economic cost-benefit analyses, which at current prices results in a break-even point of about 7-8 kg DM kg^{-1} applied. For grassland on clay and sandy soils, the recommendation is 400 kg N ha^{-1} yr^{-1}, including effective N in applied manure (Prins et al., 1988); for silage maize it is 150 kg N ha^{-1} yr^{-1}. On many farms, N inputs are higher, partly because effective N in animal manure is underestimated. As a consequence, substantial quantities of N will leach to the groundwater.

Sub-optimal growing conditions are another cause of low nutrient utilization. Quite often the expected yield, on which fertilizer application was based, is not realised, because of management errors or water stress. Hence, improving growing conditions can reduce nutrient emissions. At a given level of N input, nitrate leaching on grassland is much higher under grazing than under mowing. Hence, fertilizer application should be based on the prevailing growing conditions and the mode of exploitation of the grass.

Maize growth stops rather early in autumn, compared with grass or fodder-beets. Moreover, nutrient uptake at the end of its growing season is rather inefficient. As a result, substantial amounts of mineral N may accumulate in the soil towards the end of the year. To reduce the risk of nitrate leaching in autumn and winter, a catch crop can be grown immediately after harvest (Scott et al., 1987).

If the land is suitable for both grassland and arable cropping, the ratio of the areas of the different crops may be optimized, taking into account both the desired quantities and qualities of forages, and the possibilities to apply animal manure. For example: on soils with limited moisture supply, feed energy production per unit area of maize is higher than for grass, so from that point of view, expanding the area of maize is attractive. However, nutrient uptake is lower, so on maize land less slurry is permitted. Therefore, expanding the maize area to increase feed energy production may lead to slurry surplus and increased demand for purchased proteins, which puts a limit on that expansion.

In current practice, a large proportion of the manure of the dairy farm is used on permanent maize land. Besides, part of the slurry of pig farms is used on these fields. As a result P accumulates in the soil, whereas on fields permanently cropped with grass, purchased P fertilizers have to be applied to maintain their P status. Therefore, it is essential that the manure is distributed according to crop nutrient requirements and P status of the soils.

Forage

The proportion of farm-produced forage that is utilized by cattle should be kept as high as possible to restrict nutrient losses from crop residues and the need for purchased feeds that cause extra inputs of nutrients. In practice, losses up to 20% of the potentially 'harvestable' grass production, and about 10% of maize and fodder-beets, are common. Losses can be reduced by restricting the daily grazing time and the total grazing period per field. Better timing and methods of harvesting also will reduce losses in grass and maize considerably and improve forage quality. Generally these measures will be economically viable, though they put high demands on the motivation and skills of the farmer.

Research approach

Whole-farm system research on interactions and overall effects of integrated measures is needed for a substantial improvement in nutrient utilization. However, that presents two major methodological problems. First replicates are hardly possible, because of specific farm conditions, such as soil type and skill of the farmer. Second, these specific conditions hamper extrapolation of results to other farms. Moreover, system research is expensive because a complete farm is needed and extensive observations have to be made. An attractive solution to these problems is to combine system modelling and system prototyping. Modelling is used to generate and evaluate prototype systems (Van Keulen & Wolf, 1986; Spedding, 1990; Spedding, 1988). Prototyping is needed to validate and improve the models. Therefore an important part of the experimental work aims at quantifying flows of nutrients, especially N. That includes measurement of animal protein intake, N content of manure and ammonia volatilization, both indoors and outdoors. Also leaching, mineralization and crop uptake of N have to be measured. If models have proven to be valid, they can be used as a tool for farming systems design and development in general, thus serving as a means of 'translating' research results to other conditions.

System modelling

Models represent simplified descriptions of reality. Accurate and reliable predictions require simple models, calibrated on rather extensive data collected in the environment where the models have to be used. Comprehensive models are not suitable for predictive purposes. These models contain many functions and parameters, each with its own uncertainty, accumulating in the simulated final result. Their usefulness is more in deriving the concepts for simple, causal relationships, needed in the simple models (Spitters, 1990). Therefore, simple models have been used to describe and integrate the main components of the dairy farming system. They were used to calculate the effects of N and moisture supply on dry matter yield and N content of crops, the influence of method of manure application on ammonia volatilization, and the effects of diet composition on milk production and excretion of nutrients in urine and faeces. Some of the relationships between management practices and nutrient flows have been reliably quantified, such as the effect of slurry injection on ammonia volatilization, others are more speculative, like the influence of grazing systems on yield losses, which appear to be strongly affected by the management skill of the farmer. Examining the range of responses to this type of measures allows analysis of the effect of farmer's skill on farming results.

System prototyping

The most promising prototype, according to the initial results of modelling, will be examined in practice by a joint effort of the Centre for Agriculture and Environment, the Centre for Agrobiological Research and the Research Station for Cattle, Sheep and Horse Husbandry. Recently, the Experimental Farm for Dairy Husbandry and Environment ('De Marke') came available for this purpose. The farm is located in the east of the Netherlands on a well-drained sandy soil. It comprises 55 ha, twice the size of an 'average' farm, but necessary to produce feed for the number of cows needed for a valid experiment. Some of the environmental restrictions imposed on the farm have been quantified explicitly in government regulations, others have been derived from more generally formulated targets and converted into quantitative criteria at farm level. A reduction in ammonia volatilization of at least 70%, compared to the average situation in 1980, implies an upper limit of 40 kg N ha^{-1} yr^{-1}. For a well-drained sandy soil and an annual precipitation surplus of 300 mm, nitrate leaching should not exceed 34 kg N ha^{-1} yr^{-1}, to comply with the standard of 11.3 mg N l^{-1}. Total annual N losses, including denitrification and runoff, should not exceed 128 kg ha^{-1}. Accumulation of P should be avoided, if the P status of the soil is within the agronomically satisfactory range. If it exceeds that, the P reserves should be reduced. For the experimental farm as a whole this implies an annual permitted surplus of 0.4 kg N ha^{-1}. Moreover, all manure produced should be applied on the farm. In addition, K leaching should be minimized, pesticide and energy use limited, well-being of man and animal taken into account, and financial output maximized.

Initial results of modelling

System design

With the 'current' system (I) as a reference, an 'improved' system (II) and a 'further improved' system (III) have been designed, based on constraints and perspectives of efficient nutrient management as described above. The latter aims at meeting the environmental standards of 'De Marke'. System I can be characterized as a dairy farm on well-drained sandy soil, comparable to the 'average' dairy farm in the mid-eighties (Table 2). The risk of nitrate leaching is high on this soil, but grass and other fodder crops can be grown and slurry injection is possible. Measures to reduce nutrient losses have been selected on the basis of cost-benefit analyses. System II is characterized by more accurate management, including concentrate supply according to the individual needs of the animals and more attention to grazing, harvesting and conservation losses. The measures introduced are relatively simple and cheap, being already practiced by innovative farmers. There is one exception, requiring substantial investments: the slurry storage has to be expanded and covered. System III is characterized by additional investments and measures to further improve the efficiency of nutrient management (Tables 2 and 3).

Table 2. Characteristics of a 'current' Dutch dairy farm on sandy soil, 1983-1986, and of the same farm after (further) improvement (data on annual basis).

	'Current' farm (system I)	'Improved' farm (system II)	'Further improved' farm (system III)
milk production (kg ha^{-1})	13 195	13 195	13 195
number of cows ha^{-1}	2.3	1.9	1.5
grass (ha)	22	16	16
maize (ha)	3	9	6
fodder-beets (ha)	0	0	3
purchased fertilizer N (kg ha^{-1})	330	159	91
purchased fertilizer P (kg ha^{-1})	15	2	3
purchased concentrates (kg ha^{-1})	4 995	2 348	1 778
purchased maize silage (kg DM ha^{-1})	2 135	0	0
part of feed energy produced on the farm (%)	57	83	84

Table 3. Measures to reduce nutrient losses on a 'current' Dutch dairy farm on sandy soil.

System components/measures	'Improved' farm (system II)	'Further improved' farm (system III)
Cattle component		
– milk production	• 7 000 kg cow^{-1} yr^{-1}	• 8 500 kg cow^{-1} yr^{-1}
– young stock	• 77% of dairy cows	• 57% of dairy cows
– grazing regime	• only by day	• only by day • restricted grazing season • rotational grazing from 4 to 2 day
– diet grazing season	• additional maize silage	• additional maize silage
– diet winter season	–	• fodder-beets and corn-cob mix to replace concentrates
Manure component		
– slurry storage	• expanded and covered	• expanded and covered
– method slurry application	• injection	• injection
– time slurry application	• spring and summer	• spring and summer
– stables	–	• improved floor • dung scraper
Soil/crop and forage components		
– fertilizer for grass	• 310 kg N ha^{-1} yr^{-1}	• 235 kg N ha^{-1} yr^{-1}
– fertilizer for maize	• 145 kg N ha^{-1} yr^{-1}	• 130 kg N ha^{-1} yr^{-1}
– catch crop	• after silage maize	• after silage maize
– land use	• more maize	• more maize and fodder-beets

In systems II and III, slurry is only applied in spring and summer by injection, soon to be compulsory in the Netherlands. The costs of this measure, in terms of prevented volatilization losses, are about NLG 3.5 kg^{-1} N, twice the costs of anorganic-fertilizer N. For economic reasons the stable has not been adapted in system II. In system III such adaptations have been assumed to minimize N losses, at a cost of about NLG 23 kg^{-1} N saved. To reduce N intake, and consequently the amount of N in excrements, grazing has been changed from continuous grazing to daytime grazing only, combined with feeding of maize silage, as is common practice already at about 50% of the dairy farms on sandy soils. In system III the grazing season ends on 1 October, one month earlier than in both other systems. As grazing is restricted, more maize silage is needed in systems II and III, so grassland is partly replaced by arable land. In system III, fodder-beets and maize (corn-cob mix) partly replace purchased concentrates. In system II, grass is fertilized annually with 310 kg N ha^{-1}, including effective N in animal manure, and maize with 145 kg N ha^{-1}. In system III, where annual leaching has to be restricted to 34 kg N ha^{-1}, annual N input on grassland is reduced to 235 kg ha^{-1}. Maize is fertilized at 130 N kg ha^{-1}, fodder-beets at 170 N kg ha^{-1}. In both systems, maize is followed by a catch crop to reduce nitrate leaching. Fertilization rates of crops following a catch crop or grassland, are reduced in accordance with the expected increased N mineralization. In system III, utilization of harvestable forage is improved by a two-day rotational grazing scheme. To reduce feed requirements, annual milk production per cow has been increased from 5 700 kg to 7 000 kg (system II) or 8 500 kg (system III). In 1989, average milk production per cow was already 6 700 kg, so this improvement has been realised partially already on most farms. Increasing milk production to the level of system III cannot be realised at once, but it can be achieved by continuous genetic improvement of the cattle. In system III, the number of calves is reduced to that needed for replacement of milking cows, so meat production is minimized.

System evaluation

As shown in Table 4, conversion of N intake to milk and meat will increase from 17% to 23% (system II) or 26% (system III). Higher efficiencies could be attained by further adaptations, such as zero-grazing, lower fertilizer rates on grass, higher milk production levels or off-farm rearing of calves. However, most of these adaptations will increase costs of milk production considerably.

As a result of improved manure management in the improved systems, a higher proportion of N from the excrements reaches the soil component (82% and 90%, compared to 73% in system I). This results, in combination with the lower N contents of excrements, in a sharp decline in ammonia losses from manure: from 101 kg N ha^{-1} to 50 kg N ha^{-1} and 21 kg N ha^{-1}, respectively. Similarly, reduced inputs and improved utilization of nutrients lead to a strong reduction in nutrient surpluses from the soil/crop component: from 325 kg N ha^{-1} to 113 kg N ha^{-1} and 77 kg N ha^{-1}, respectively; and from 29 kg P ha^{-1} to 0 kg P ha^{-1} for both systems. Lower fertilization rates on grass, and replacement of grass by fodder crops lead to lower average protein production per hectare but total dry matter production on the farm is hardly

Table 4. The model-calclulated annual nutrient balances (kg ha^{-1} yr^{-1}) of a 'current' Dutch dairy farm on sandy soil, 1983-1986, and of the same farm after (further) improvement.

	'Current' farm (system I)		'Improved' farm (system II)		'Further improved' farm (system III)	
	N	P	N	P	N	P
Cattle component						
input:						
– purchased feed	178	31	63	12	58	10
– forage	313	42	293	42	234	35
output:						
– milk	68	12	68	12	68	12
– meat	16	5	12	4	8	2
output/input	17%	23%	23%	30%	26%	31%
Manure component						
input:						
– excrements during grazing	191	25	88	11	62	8
– excrements indoors	198	30	185	28	151	23
output:						
– excrements reaching soil	164	25	76	11	56	8
– manure applied	120	30	147	28	136	23
input - output	105	0	50	0	21	0
output/input	73%	100%	82%	100%	90%	100%
Soil/crop component						
input:						
– excrements reaching soil	164	25	76	11	56	9
– manure applied	120	30	147	28	136	23
– artificial fertilizer	330	15	159	2	91	3
– atmospheric deposition	46	1	45	1	45	1
– returning forage losses	63	6	24	3	19	3
output:						
– harvestable crop	398	48	338	45	270	38
input - output	325	29	113	0	77	0
output/input	55%	62%	75%	100%	77%	100%
Forage component						
input:						
– harvestable crop	398	48	338	45	270	38
output:						
– consumed forage	313	42	293	42	234	35
input - output	85	6	45	3	36	3
output/input	79%	87%	87%	93%	87%	93%
Whole farm						
input:						
– artificial fertilizer	330	15	159	2	91	3
– purchased concentrates	136	25	63	12	58	10
– purchased roughage	42	6	0	0	0	0
– deposition	46	1	45	1	45	1
– miscellaneous	7	0	4	0	4	0
output:						
– milk	68	12	68	12	68	12
– meat	16	5	12	4	8	2
input - output	477	31	191	0	122	0
output/input	15%	35%	30%	100%	39%	100%
volatilization: from manure	105		50		21	
nitrogen accumulation in soil	30		0		0	
leaching/denitrification	286		117		82	
other losses	56		24		19	

affected, because of the higher yields of fodder crops on soils with a limited water-supplying capacity. The adapted grazing system and reduced harvest losses lead to increased utilization of forage nutrients. At farm level, the annual surplus of nutrients already decreases sharply in system II: from 477 kg N ha^{-1} to 191 kg N ha^{-1}; and from

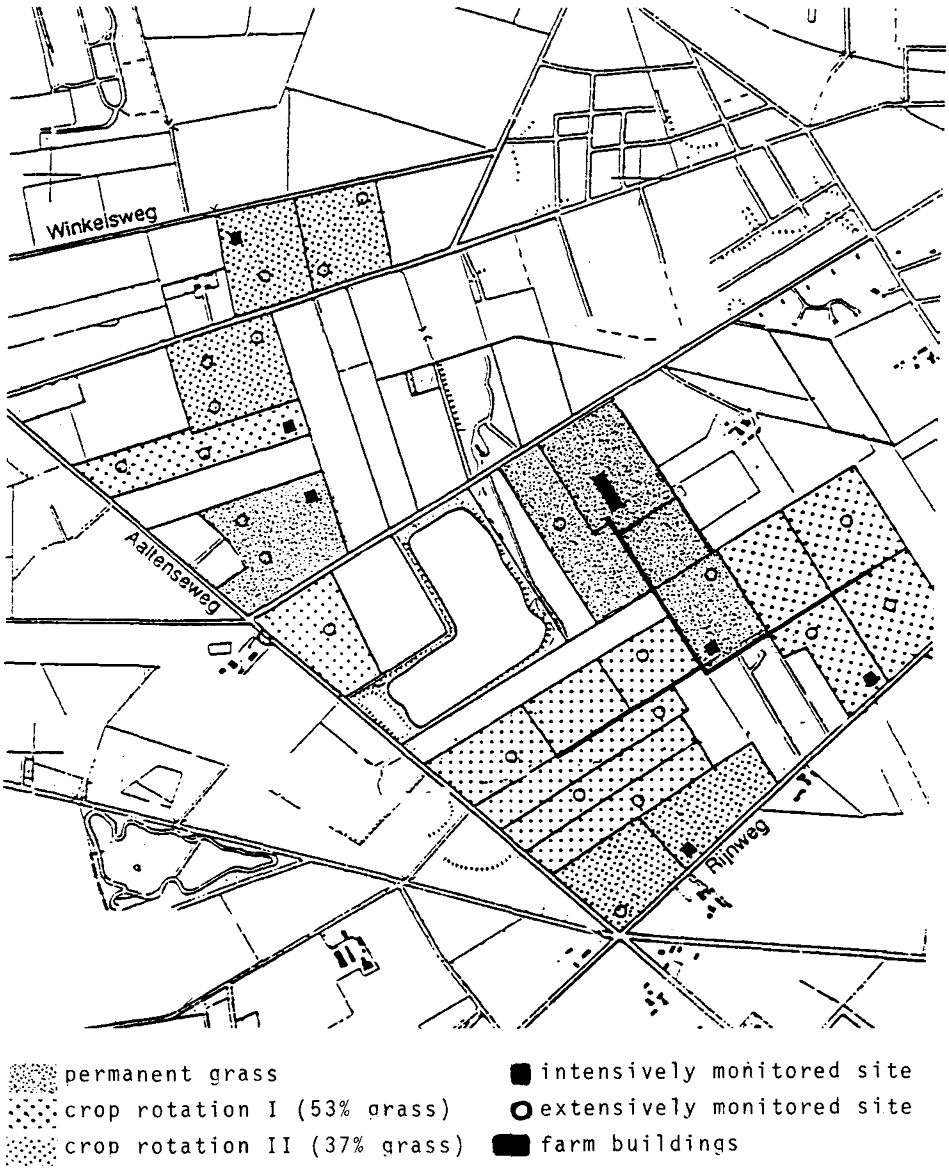

Fig. 2. Plan of 'De Marke'.

31 kg P ha^{-1} to 0 kg P ha^{-1}. In system III, N losses even decline to 122 kg ha^{-1}, just below the 128 kg ha^{-1} aimed for. Most of the N surplus is lost by leaching and denitrification. In system I, annual leaching is approximately 135 kg N ha^{-1}, and in the improved systems 44 kg N ha^{-1} and 28 kg N ha^{-1}, respectively.

Layout of the prototype system

Based on the initial results of model calculations, system III was selected as the prototype system to be examined on the experimental farm 'De Marke'. The farm area was divided into permanent grassland and two crop rotations, varying in the ratio of grass to arable crops (Figure 2). Most grassland is situated near the farm buildings, favourable from a farm management point of view, as the cows are milked indoors. Nevertheless, arable crops can be alternated with grass, for example to reduce soil-borne diseases. To recover nitrogen mineralized after ploughing the grassland, fodder-beets are grown first, because of their higher N uptake capacity compared to silage maize. Only permanent grassland and grass in rotation I will be irrigated if urgently needed for grazing.

Yields of arable crops are assessed per field. Grass yield is estimated by measuring silage yield and calculating intake of the grazing herd. More detailed information is collected by monitoring the soil-crop system at 28 permanent sites, six of which are monitored intensively. On permanent grassland and on each of the rotations two 'intensive' sites are situated, one on a field with a relatively shallow groundwater level, influencing soil water supply to the crop, and one on a field with a deep groundwater level. On the 22 less intensively monitored sites, soil mineral N is measured (in spring and autumn), crop phenological development is estimated (weekly), crop yield and nutrient contents are quantified (at harvest) and soil fertility is analysed (every three years). At the intensively monitored sites information is collected more frequently and additional observations include: soil-water content, soil-water tension, groundwater depth, nitrate concentration in drain water and soil temperature. Meteorological data, including rainfall, radiation, relative humidity, wind speed and temperature are recorded near the farm buildings.

Plot experiments, such as varying N fertilization levels, are only acceptable insofar their influence on performance of the prototype system is acceptable. Within that restriction, detailed experiments can provide important information about, for example, N leaching as a function of the fertilization level.

Perspectives

The calculated results for the 'improved' system (II) illustrate that nutrient losses may be reduced considerably by more accurate management and the introduction of an integrated set of cheap and profitable measures into existing farming systems. As the improved system does not fully meet the environmental goals with respect to N, further steps are necessary. However, the performance of system III suggests that environmental standards can be attained, even at a relatively high milk production level per hectare.

From agricultural practice, results have been reported from farms reducing the N surplus within a couple of years by 25-50% (Korevaar, 1992), mainly by better utilization of roughage, hence reduced concentrate input and reduced fertilizer input, partly compensated by better utilization of animal manure.

First steps in farm development towards integrated farming systems seem at least cost-neutral and may even be profitable because of lower inputs. Subsequent steps need more skill and are more expensive. However, preliminary calculations on the financial results of system III suggest an acceptable income, provided milk prices remain stable. Therefore, most dairy farms characterized by average or below-average milk production per hectare have rather favourable prospects. However, farms that are very dependent on purchased feed either have to reduce milk production per hectare or export animal manure. Under present Dutch conditions of substantial manure surpluses, reducing milk production seems the least expensive.

The experimental farm 'De Marke' aims at development of advanced prototypes of integrated farming systems. Subsequently these prototypes will be introduced on commercial farms for testing and further improvement. Introduction of the systems on a large scale requires the support of extension and education, and a stimulating environmental policy. Registration of inputs and outputs of nutrients at farm level was started in the Netherlands in 1990 on a voluntary basis, as a first step. In addition an adequate system of levies and premiums should be introduced to accelerate transition from the current farming systems to integrated systems with due attention to different goals.

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