De Marke

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Efficient nutrient management in dairy farming on sandy soils

Technical results of the experimental farm "De Marke" for the years 1993/94 and 1994/95

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Abstract

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On most Dutch farms input of nutrients in manure and feed strongly exceeds output in milk and meat, causing environmental problems. Research on 'De Marke' focuses on the question to what extent optimizing nutrient management can be a solution. The results sofar suggest that, even on dry sandy soils and 12,000 kg milk/ha, strict environmental requirements with respect to nutrient losses can be met. As a result of optimal utilization of animal manure the use of inorganic fertilizers could be reduced by 75% and the input of nutrients in purchased fodder by 50%.

Key words: dairy farming, environment, sandy soil, nitrogen, phosphorus, nutrient, nutrient balance.

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Summary

On the average dairy farm on light sandy soils the input of nutrients in manure and feed strongly exceeds the output in milk and meat. The difference - the surplus - will have an impact, sooner or later, on the environment. The project 'De Marke' does not aim at extensification as a possible solution to this problem, as that generally is too expensive under Dutch conditions, but focuses on the question to what extent optimizing nutrient management offers possibilities.

In this research project the method of 'prototyping' is being used. First, farming systems were identified that, in theory, meet the formulated objectives. One of the technically and economically most attractive systems was then implemented at the experimental farm 'De Marke' in 1992 and subsequently further developed. The functioning of this prototype system is described as completely as possible in quantitative terms by measuring flows of materials (like slurry and fodder) and nutrients.
The results sofar suggest that, even on dry sandy soils at 'current' milk quota, within a short time, strict environmental requirements with respect to the loss of nitrogen (nitrate and ammonia) and the accumulation of phosphate can be met. The concentration of nitrate in the upper groundwater decreased within a few years by 75 % to a value just below the norm of 50 mg nitrate/l. Per hectare only 22 kg N was lost as ammonia and the input of phosphorus in purchase fodder approached the output via milk and cattle. The nutrient flows realized in the farming system corresponded well with the values calculated on the basis of existing knowledge. Intake of N and P by the cattle, however, was considerably higher than expected. Nevertheless, input of nutrients in purchased fodder could be reduced by 50 % compared to that for a current farm in the mid-eighties.

As a result of optimal utilization of animal manure and lower levels of nutrient application, the use of fertilizer-N could be reduced by 74 % compared to current practice and the use of fertilizer-P could be completely avoided.

When calculating the annual surplus of nitrogen at farm level, in principle the change in the total soil store would have to be taken into account. This change can, however, not be determined accurately. Under favourable soil moisture conditions the rate of decomposition of organic material is higher than under drier conditions, thus leading to higher rates of nitrogen mineralization. Hence, a high surplus of nitrogen in a dry year may have a much smaller impact on the environment than a much lower surplus in a wet year.

Due to the low P-surplus, phosphate availability for the crop was reduced. This has caused problems in some of the plots during early growth of maize. These problems can probably be avoided in the future by applying slurry after ploughing, preferably in the crop rows, so that the plant roots have more easy access to the P in the slurry.

To obtain reliable results, research has to be continued for quite some time, as the system has to stabilize, soil nutrient stores and soil fertility react slowly to changes in farm management and weather conditions are always variable. There are, however, no reasons to expect major problems in the immediate future.

1. Introduction

On the average dairy farm on light sandy soils the input of nutrients via purchased fertilizers and feed strongly exceeds the output in milk and meat (Van Eck, 1995; Oenema & Van Dijk, 1994). The difference - the surplus - sooner or later will have an impact on the environment. Water will be polluted as a result of run-off and leaching of nitrate and phosphorus. Atmospheric deposition of ammonia can lead to acidification and contributes to eutrophication. This may lead to destruction of ecosystems and damage to our cultural-historical inheritance. Government policy aims at reducing nutrient losses to environmentally acceptable levels. Dairy farmers will try to minimize the costs associated with government policy, for which they need sufficient and reliable information. Agricultural research must provide the dairy farmer timely with the necessary information, to which the project 'De Marke' contributes.

2. Objective project 'De Marke'

A dairy farm can meet the environmental objectives of the government by extensification, i.e. by producing less milk per hectare (Weissbach & Ernst, 1994). For a given milk quota, more land will then be needed, which especially in the Dutch sandy areas is scarce and expensive. In The Netherlands, land taken out of production is mainly used for nature development and extension of infrastructure. Extensification without area expansion leads to reduced milk production, and hence to a strong decrease in income. Moreover, it is doubtful whether the growing world population can be provided with enough high-quality food in the future with a reduction in the area of cultivated land and more extensive land use. In the coming decades doubling of food production is expected to be necessary. Hence, the project 'De Marke' does not aim at extensification as the solution to environmental problems, but focuses on the question to what extent optimizing nutrient management of dairy farms offers opportunities to maintain a high milk production per hectare.

Characteristic for the dairy farm is the combination of plant and animal production. Animal manure and roughage form the links between the animal and the plant component. Nutrients that are not exported - in milk and animals - or lost, pass through a cycle: nutrients from the fodder are excreted by the animals in faeces and urine. This manure is used in crop cultivation, nutrients from the manure are taken up by the crop and then again consumed by the cattle. Nutrients exported in milk and animals and lost in the cycle are compensated by the input of nutrients in purchased fertilizers and animal feed.

Nutrient flows can be influenced by management, thus reducing losses. At most farms cattle take up much more nitrogen than is necessary physiologically. Hence, a reduction in the nitrogen content in the ration will hardly affect milk production, but will lead to smaller quantities of nitrogen in the urine which will generally lead to lower losses. It is important that, wherever possible, measures in the different parts of the cycle are mutually synergystic, and are geared to the specific possibilities and limitations of the farm. Cost minimization is an important criterion.

The objective of this project is to design, test and further develop a farming system, that can serve as a starting point for the development of dairy farms on dry sandy soils with an average milk production (about 12,000 kg/ha). The farming system should meet the strict environmental norms derived from policy papers. This implies that groundwater may contain only 50 mg nitrate per litre - on light sandy soils it is now often more than 200 mg/l (Boumans & Van Drecht, 1995) - and that ammonia emission from faeces and urine should be limited to 30 % of the average emission in 1980, i.e. an annual loss of 30 kg NH_3-N/ha at most. P-surplus - now some 30 kg/ha annually - should not exceed 1 kg/ha (Oenema & Van Dijk, 1994). To avoid desiccation, the use of groundwater should be limited. Hence, irrigation is only permitted to allow grazing during part of the day (because of reasons of animal wellfare) or to prevent early dying of crops due to drought. The latter may have negative effects on utilization of already applied fertilizers (environmental considerations), and it may require purchase of larger quantities of fodder (economic and environmental considerations). Manure production is restricted to the amount that can reasonably be applied at the farm.

3. Research methodology

In the research project the method called 'prototyping' is being used. First input-output relations have been established for the animal and plant components of the farm, using existing and specially developed and adapted calculation programmes. This referred, among others, to the relation between daily milk production per animal and the required amounts of energy, protein and phosphorus, and to that between crop yield and the required amounts of fertilizers and water (Aarts et al., 1992; Biewinga et al., 1992). These relations have been used for the design of a number of farming systems that, in theory, meet the formulated objectives.

From the set of systems that are theoretically acceptable, one of the technically and economically most attractive and most interesting from a research point of view was implemented at the experimental farm 'De Marke' in 1992. Subsequently, it was further developed with the aim to more fully realize the objectives. The functioning of this system - also called 'De Marke' - is described as completely as possible in quantitative terms by measuring, wherever possible, flows of materials and nutrients. Moreover, detailed observations are carried out at a number of fixed sites, to increase insight in the processes that take place in the soil, mainly with respect to water, organic matter, nitrogen and phosphorus.

The selected research method has some important advantages. The scientific approach to production systems concentrates at the farm level, the level at which management operates. The integrated effect of processes is illustrated, and the transfer of the knowledge acquired is facilitated, as the functioning of the system can be directly observed. By building a bridge between theory and experimental testing the risk is reduced that, in desk-studies, too much attention is paid to elements that appear to be less relevant in practice or - the other way around - that insufficient attention is paid to issues that appear to be important later. Prototyping also has some disadvantages. The experimental system has been selected rather subjectively from a number of options, and reliable comparison with other systems is impossible, since only one system can be implemented, and even that system is continuously developing. Therefore, the results cannot be tested statistically. These disadvantages can partly be overcome by using an appropriate monitoring programme and additional (inter)disciplinary research, aimed at determination of causal relations that explain the behaviour of the system, and can be used to investigate the consequences of alternatives. Prototyping is also expensive. Implementation of the experimental system at 'De Marke' required an investment of 10 million guilders and the annual research costs amount to about 1 million. The Ministry of Agriculture, Nature Management and Fisheries (LNV), the Ministry of Health, Physical Planning and Environment (VROM) and the agricultural sector finance the research. The Institute for Agrobiological and Soil Fertility Research (AB-DLO), the Centre for Agriculture and Environment (CLM) and the Research Station for Cattle, Sheep and Horse Husbandry (PR) are the initiators and executors of the project.

4. Experimental farm 'De Marke'

To test the theoretically acceptable farming system, 55 hectares of land were bought in De Achterhoek, in the eastern sandy part of The Netherlands. Hence, the experimental farm has almost twice the size of the average farm in the sandy areas. This large area is necessary for research reasons: to obtain sufficiently reliable results, more animals are needed than on the average farm and this requires a greater feed supply.

The land comprising the experimental farm 'De Marke' was probably reclaimed from heather around the turn of this century. An upper layer of 25 to 30 cm with an organic matter content of on average 4.9 % overlies a layer of practically humusless sand. The groundwater table is at most places so deep that water cannot reach the root zone. The waterholding capacity is therefore less than 50 mm on 60 % of the cultivated land and for the remainder it varies between 50 and 100 mm. Hence, the land of 'De Marke' belongs to the driest 10 % of the sandy soils in The Netherlands.

The plots of 'De Marke' were acquired from various landowners. Thus, they had a different history with respect to the application of animal manure, resulting in considerable differences in soil fertility, especially for phosphorus. Most of the land was bought in 1989. Until the system research started in the spring of 1992, the crops received small amounts of artificial fertilizer. Grazing nor irrigation took place during those years.

5. Experimental farming system 'De Marke'

The main characteristics of the experimental farming system are summarized in Tables 1 and 2. A comparison is made between the expected values of these characteristics (prognoses) - the results of the model calculations at the basis of the farming system design - and the realized results in the financial years (May 1 until May 1) 1993/1994 and 1994/1995. The experimental system started in the spring of 1992, but as the herd was not complete then, the results of the first financial year have not been considered. The 'average' farm from the middle of the eighties is taken as reference (henceforth referred to as 'the current farm'), as a discontinuity occurred at that time: because of the introduction of milk quota a further increase in national milk production was impossible, and farmers were confronted with legislation directed at reducing nutrient losses.

Common practice on dairy farms in The Netherlands has changed since the middle of the eighties, mainly because of the introduction of environmental laws. Therefore, comparison of the results of 'De Marke' with those of the current farm from the middle of the eighties has only limited value. Hence, the most relevant developments in actual practice are described in the text.

5.1. The cattle component

The milk quota of the current farm was slightly higher than that of 'De Marke', but reductions in the second half of the eighties have resulted in a comparable quota at the beginning of the nineties. Model calculations suggest that the feed requirements of a farm for a given milk quota decrease when milk production per cow increases, because per kg of milk less energy is needed for maintenance of the animals and less young stock is needed for replacement (at a similar life span). Hence, the aim at 'De Marke' was to realize a considerably higher milk production per cow than the current farm. That higher level appeared attainable and has resulted in a much lower stocking rate. In the meantime, also in practice on many farms, milk production has increased to over 7,000 kg/cow.
The higher milk production has not resulted in the savings on feed as expected on the basis of the model results. The energy intake (kVEM*) of the dairy cattle appeared substantially higher than expected on the basis of the feeding standards, without the animals showing signs of fattening (Meijer, 1994). The production range for which the models were developed originally, goes up to about 6,500 kg/cow (pers. comm. A. Meijer, PR). It appears, therefore, that the saving on feed at high production levels is less than expected on the basis of the model results.

The number of young stock per milking cow appeared higher than foreseen in the farm plan and was on average practically similar to that on the current farm. In the last financial year, however, the number of young stock was definitely lower at 'De Marke'. In practice, the number of young stock per milking cow increased to one in the sandy areas (Leneman et al., 1996).

Table 1 Characteristics of the cattle component of an 'average' farm in the middle of the eighties (reference situation), the prognoses at the start of 'De Marke' and the realized characteristics in the financial years 1993/1994 and 1994/1995

Characteristic	'average' 1983/86	'De Marke'		
		prognoses	1993/94	1994/95
real milk production (kg/ha)	12,798	11,890	12,047	11,664
FPCM* (kg/ha)	13,161	12,487	12,681	12,288
milking cows/ha	2.31	1.47	1.45	1.43
FPCM/cow (kg)	5,697	8,495	8,720	8,467
young stock/cow	0.76	0.57	0.81	0.70
purchased concentrates (kg dm/ha)	4,047	1,377	1,544	1,542
purchased roughage (kg dm/ha)	2,136	0	251	693
feed intake cattle (kg dm/ha)	16,158	11,240	12,726	11,495
feed intake cattle (kg dm/kg FPCM)	1.23	0.90	1.00	0.94

* fat and protein corrected milk

The main reason for the higher number of young stock at 'De Marke' in the financial year 1993/1994 was the fact that the herd was in the building-up phase, requiring additional possibilities for selection. Therefore, the number will probably decrease in the coming financial

* 1.0 kVEM = 6.9MJ Net Energy for location

years. Because of the high energy requirements of the dairy cattle, in comparison to the feeding standards, and the high number of young stock, dry matter intake per unit of milk production during the first year was 11 % higher than predicted, but still considerably lower than at the current farm. In the second year, feed intake was only 4 % higher than predicted.

In formulating the ration, the aim is to minimize protein and phosphorus contents. The consequences for the N- and P-contents in animal manure will be described later (Sections 6.2 and 6.3). At 'De Marke' animals are taken out of pasture about one month earlier than at the current farm and daily grazing time is restricted. In summer, the cows are stabulated during the afternoon and the night and are supplemented indoors with maize. In the first year the cows were stabulated at night only, but the periods of availability of protein-rich (daytime grazing) and protein-poor feed (maize at night) appeared too long and led to digestive problems in the highly productive cattle. The dairy cattle are moved to a new plot every two days, after which the pasture is further grazed by young stock. Restricting grazing time results in less urine and manure patches. Nitrogen from these patches is lost to a large extent, especially when they are produced late in the season. Restricted grazing results in a larger part of the faeces and urine being produced indoors. Their nutrients can be utilized much more efficiently.

As manure is spread on the land only between the beginning of March and mid-August, the required storage capacity at 'De Marke' is substantially higher than at the current farm, that did not face any restrictions on manure application in the middle of the eighties. However, the time during which manure can be spread at sandy soils now has been limited to the period between February 1 and September 15, hence the required storage capacity at the current farm has also increased.

5.2. The soil/crop component

The area of the different forage crops is determined on the basis of a compromise between the production capacity of the crops under the conditions of 'De Marke', the value of their products in the ration and the possibilities to use animal manure efficiently.

The proportion of grass in the rotation at 'De Marke' is lower than at the current farm, and the proportion of maize consequently higher (Table 2). The main reason is the demand for energy-rich feed with a low nitrogen content, to compensate for the rather high nitrogen contents in the grass products in the ration. Incorporation of this energy-rich material in the ration reduces the output of nitrogen in urine and faeces. Supplementary feeding with maize serves as an energy buffer and, moreover, limits the risk of grass tetany during the grazing season. Maize silage has a higher energy content than grass silage, implying that less concentrates are needed in the winter period. Moreover, the water and nutrient requirements of grass per unit harvestable dry matter are much higher than those for maize and fodder beets (Aarts & Grasshof, 1993). Moisture availability at 'De Marke' is generally the most limiting factor for crop growth and yield. At 'De Marke' the aim is to minimize water use for irrigation, especially because groundwater is a scarce resource, but also because it requires energy and labour. Nevertheless, also at 'De Marke' the area of grassland exceeds that of arable land. Important reasons are the higher yields of N and P (import of these elements in purchased feeds should be limited), the possibilities for grazing and the greater opportunities to use animal manure. Moreover, grassland stimulates soil organic matter build-up and therefore indirectly soil moisture supply. In recent years, the proportion of maize in the rotation at current farms also has increased and the situation at 'De Marke' is not really an exception anymore. In the financial year 1992/93 the ratio of the areas of grassland and maize at dairy farms in the sandy areas was about 3:1 (Leneman et al., 1996).

Fodder beets are hardly grown in actual practice, but at 'De Marke' they can replace part of the necessary concentrates. Moreover, the yield of dry matter and energy per hectare is as a rule very high and the nitrogen uptake capacity exceeds that of maize, so that beets as first crop after the grassland period is considered safer than maize. Large amounts of beets in the ration for highly productive dairy cattle appeared to lead to digestive problems. Hence, after the first year the proportion of beets in the ration in winter was reduced, and part of the beets was ensiled with maize, so that it could be incorporated in the summer ration. An important disadvantage of that practice is that the beets have to be harvested early, hence at a lower dry matter yield, and cultivation of a catch crop is necessary (to take up the nitrogen mineralized after harvest). Despite incorporation of the beets in the summer ration, the original area of beets (6 ha appeared too large) for judicious feeding practice, and it was reduced to 4 ha in 1994.

At 'De Marke', part of the maize is harvested as corn cob mix (CCM) which is very high in energy and mainly used as concentrate replacer for the most productive animals. Maize stover is also harvested and used as absorbing bottom layer for the rather wet grass silage in autumn. The silage is then covered with beet leaves. This silage appeared to be very suitable for feeding young stock and dry cows. Also in current practice CCM is increasingly used, but the stover is not (yet) harvested. In practice less autumn grass is being ensiled, as grazing continues one month longer as a rule.

Table 2 Characteristics of the crop component of an average dairy farm in the middle of the eighties, the prognoses at the start of 'De Marke' and the characteristics realized in the financial years 1993/94 and 1994/95

Characteristic	'average' 1983/86	'De Marke' prognoses	1993/94	1994/95
Area (% of total):				
- grassland	90	56	55	60
- maize	10	33	34	32
- fodder beets	0	11	11	8
Artificial fertilizer (kg/ha)				
- N	331	67	52	96
- P	15	6	2	0
- K	30	25	38	0
N-fixation clover (kg/ha)	0	30	12	5
Net yield* (kg dm/ha):				
- grass	9,942	9,276	9,409	8,792
- maize	10,274	11,167	10,657	9,276
- beets (leaf included)	--------	14,133	16,583	10,064
- average of farm	9,975	10,436	10,615	9,046

* net yield is the yield after subtraction of grazing, harvesting, conservation and feeding losses, and thus equals animal intake

From the total of 31 ha in grassland, 22 ha is used for ley farming and 9 ha is permanent pasture. Ley farming improves soil fertility during the period of arable farming. Continuous arable farming leads to a lower soil organic matter content than ley farming, which eventually results in increased drought sensitivity. It is well-known that the yield of maize under ley farming is higher than under continuous maize - certainly when continuous cultivation has not taken place yet - and that the risk of build-up of weed populations (through selection or build up of resistance) is smaller. Moreover, during the grass period herbicides, used on the arable crops, can decompose. Grass/clover mixtures were always sown immediately after harvest of the maize. Therefore, clover entered the winter period in the seedling stage and appeared very sensitive to frost periods, causing clover density to be strongly reduced after most winters. Consequently, nitrogen fixation by clover in both financial years was substantially lower than expected. Sowing in spring may help to overcome this problem. After three years, the grass sward is broken up in early spring . Subsequently, fodder beets are grown - because they can use the nitrogen mineralized from the decomposing grass very efficiently - followed by two (home plot) or four (field plot) years of maize. Additional research at 'De Marke' has shown that cultivation of maize after three years of grass is also possible, when no artificial fertilizer is applied: mineral nitrogen in the soil did not reach alarmingly high levels, and the quality of the groundwater was not different from that under other plots.

Fertilizer application is plot-specific and based on the uptake capacity of the crops. Soil moisture supplying capacity and the place of the crop in the rotation are taken into account. For phosphorus the principle of 'equilibrium fertilization' is applied, i.e. no more should be applied than taken up by the crop. However, during the grassland period fertilizer application exceeds crop uptake, during the arable period it is lower. In a situation of ley farming a larger part of the N-requirement of grassland can be covered by slurry, because on grassland P in slurry is more restrictive than N and on leys higher quantities of P are allowed. On permanent arable land the quantity of N in the manure is, as a rule, restrictive for the quantity of slurry that can be applied and adding fertilizer P may be necessary. Because of the system of ley farming, the phosphorus requirements of the crops can almost completely be covered by animal manure. On average, during the two financial years at 'De Marke', only 74 kg N/ha from fertilizer were required, i.e. about one quarter of that on a current farm around 1985. Since the current farm fertilizer-N use has decreased by some 40 kg/ha, because of a higher efficiency of nitrogen from slurry as a result of low- emission application techniques, thus reducing the difference between 'De Marke' and actual practice.
In 1993 and 1994, permanent grassland was manured on average with 47 tons of cow slurry/ha and 136 kg fertilizer-N/ha (in total 237 kg of mineral N/ha). Leys received 75 tons slurry/ha and 123 kg fertilizer-N/ha (in total 289 kg of mineral N/ha). Maize and beets were fertilized with 27 and 34 tons of slurry/ha, respectively (65 and 85 kg of mineral N/ha). On both grassland and arable land, slurry was applied by injection.

Between the rows of maize Italian ryegrass was sown in June, to take up the nitrogen mineralized during the ripening phase and after harvest of the maize. In all years cultivation of this catch crop appeared to be a safe and effective method. In the spring of 1995 the grass was grazed by young stock, in the earlier years it was ploughed in.

Grassland was only irrigated when necessary to allow grazing also in dry periods or to avoid re-sowing. Beets and maize were irrigated only when there was a risk of premature death. Therefore, irrigation has never resulted in completely avoidance of water shortage. The field plot of the farm - 29 % of the total area with a relatively high proportion of arable crops - was never irrigated. During dry years - as 1994 - on average about 50 mm/ha related to the total area of the farm, was applied. About 90 % of the irrigation water was used on grassland and 10 % on maize land.

The growing season 1993 (financial year 1993/94) was characterized by a warm and dry spring and a wet summer. During that year on average only 9 mm of irrigation water was applied (only on grassland). Spring of 1994 was cold and wet and was followed by a very dry summer. In Table 2 the net yields of crops are given. For silage of maize, beets and grass, dry matter yield was determined on the weighing bridge. It was assumed that during conservation and feeding an additional 7 % is lost. Intake of pasture grass was estimated by visually estimating standing dry matter at the beginning and the end of the grazing period, and assuming a daily growth rate of 50 kg dry matter/ha during grazing. In 1993, this estimated intake appeared 6 % higher than that determined from the calculated feed requirements and the intake during stabulation, and in 1994 2 % lower.

In both financial years, realized net dry matter yield of grassland was close to the prognoses for an average year. Yield of maize in 1993 was slightly below the expected value, and in 1994 was strongly reduced by drought. Yield of beets in 1994 was substantially lower than in the preceding year, when it was clearly higher than the prognoses for an average year. This lower yield was not only caused by drought (beets were not irrigated) but also by an attack of rhizoctonia and early harvest, as part of the beets were ensiled with maize. The differences in yield among crops appeared in accordance with the expectations. Although the yields of grass and maize were on average lower than those on current farms, average farm yield is almost equal, because of a higher proportion of fodder beets and maize on the farm. Analyses, carried out by the Laboratory for Soil and Crop Testing, indicated that the feeding value of the products was on average slightly higher than that of the average of samples from practice.

6. Nutrient flows

The main nitrogen and phosphorus flows in the two financial years will first be discussed for the farm as a whole and subsequently per farm component. Average N and P flows for the two financial years of the experimental farm and those for the average farm in the middle of the eighties are presented in Annexes 1a to 1d.

6.1. Farm level

The N and P balances of the farm are presented in Table 3. The prognoses was that the surplus at farm level would decrease from 487 kg N en 32.0 kg P/ha (surpluses at current farms) to 122 kg N and 0.0 kg P, respectively. The N surplus in the financial year 1993/1994 (140 kg N/ha) was close to the expected value, but it was clearly higher (198 kg N/ha) in the subsequent year, due to the higher fertilizer application rate and the reduction in the stock of slurry. The surplus of P was lower in 1994/1995 than in the year before, but it was still positive. If the changes in stock of slurry are disregarded, the P surplus in 1994/1995 is slightly negative, so in that financial year slightly more P was exported from the farm in milk and cattle than imported in fertilizers and feed. As the import of P in feed appeared higher than expected, application of fertilizer P was discontinued from the spring of 1994 onwards. Because of autonomous developments (especially legislation with respect to low-emission application techniques and the increasing milk production/cow), N surplus at the current farm has decreased by about 80 kg N/ha (17 %) and so it is now about 400 kg N/ha (Van Eck, 1995). The P surplus remained almost the same (30 kg P/ha; Oenema & Van Dijk, 1994).

Table 3 N and P balances of an average farm in the middle of the eighties, the prognoses at the start of 'De Marke' and the values realized in the financial years 1993/1994 and 1994/1995 (kg/ha)

Characteristic	'average' 1983/86		'De Marke' prognoses		'De Marke' 1993/94		'De Marke' 1994/95	
	N	P	N	P	N	P	N	P
Input:								
- fertilizer	330	15.0	67	6.0	52	1.8	96	0.0
- feed	182	32.0	41	5.9	82	15.0	84	11.5
- deposition	49	1.0	49	0.9	49	0.9	49	0.9
- N-fixation clover	0	0.0	30	0.0	12	0.0	5	0.0
- various	7	0.0	5	0.0	4	0.0	4	0.0
Sum input	568	48.0	192	12.8	199	17.7	238	12.4
Output:								
- milk	68	12.0	62	10.6	65	10.5	64	10.6
- meat	13	4.0	8	2.2	10	3.0	9	2.7
- feed	0	0.0	0	0.0	8	1.2	0	0.0
- mutation cattle	0	0.0	0	0.0	0	0.2	0	0.1
- mutation manure in storage	0	0.0	0	0.0	11	-1.0	-50	-6.4
- mutation feed stock	0	0.0	0	0.0	-35	-2.3	17	0.8
Sum output	81	16.0	70	12.8	59	11.6	40	7.6
Input - Output*	487	32.0	122	0.0	140	6.1	198	4.8

* accumulation in soil and losses to air and (ground)water

6.2. The cattle component

The difference between input and output in Table 4 represents excretion by the animals. At the current farm it was more than 400 kg N/ha. Only 16 % of the N consumed by the animals was converted into milk and meat, and the remainder is excreted in faeces and urine. It was expected that at 'De Marke' the excretion could be reduced by 50 %, by increasing the utilization efficiency at animal level to 25 % through a low protein ration, a high milk production per cow and a reduction in the number of young stock (young stock use N relatively inefficiently). The realized utilization efficiency was only 22 %, as a result of the higher protein content in the ration - protein intake was more than 18 % higher than expected on the basis of the feeding-standards (Meijer, 1994) - and a higher number of young stock. The utilization of P was also lower than expected, but the difference was smaller than for N.

Table 4 Nutrient flows of the cattle component of the average farm in the middle of the eighties, the prognoses at the start of 'De Marke' and the values realized in the financial years 1993/1994 and 1994/1995 (kg/ha)

Characteristic	'average' 1983/86		'De Marke' prognoses		'De Marke' 1993/94		'De Marke' 1994/95	
	N	P	N	P	N	P	N	P
Input:								
- feed	496	74.0	278	40.1	336	47.1	330	43.6
Output:								
- milk	68	12.0	62	10.6	65	10.5	64	10.6
- meat	13	4.0	8	2.2	10	3.0	9	2.7
- mutation cattle	0	0.0	0	0.0	0	0.2	0	-0.1
Input - Output (= faeces + urine)	415	58.0	208	27.3	261	33.4	257	30.6

6.3. The manure component

The quantities of N and P in faeces produced indoors have been determined as volume times contents. The quantities in faeces and urine excreted during grazing have been estimated from the input in fodder by subtracting the output in milk and meat and the production estimated indoors. This calculation procedure may lead to relatively large inaccuracies in the partitioning of nutrients between stable and pasture.

The quantities of nutrients in faeces and urine produced in excess of what was expected on the basis of model calculations, appear to have been produced indoors. Manure production at pasture was in agreement with the prognosis. By restricting grazing time at 'De Marke' to about one third of current, excretion of nutrients at pasture was on average only 22 % (N) and 17 % (P) of the total. In calculating the results for the current farm, day-and-night grazing was assumed during half of the grazing season (during the other half day-grazing only), resulting in 50 % of the nutrients in faeces and urine to be produced at pasture.

The difference between input and output of nitrogen in the manure component represents volatilization of ammonia from the stable, at pasture, during storage and during application. Ammonia emission has not been measured yet at 'De Marke', so it had to be estimated. Therefore, the proportion of N-losses as ammonia is set equal to that in the model. In absolute terms, the losses were 3 to 4 kg/ha higher, because more nitrogen was excreted by the animals. At the average farm in the middle of the eighties manure was still surface-applied. Combined with a much higher N-excretion, this resulted in a loss of 105 kg N/ha as ammonia. Due to the compulsory injection of manure, ammonia emission at current farms will have decreased at this moment by about 40 kg N/ha (Lekkerkerk et al., 1995). On 'De Marke', of the total loss of about 22 kg N/ha - from faeces and urine - 4 kg was lost during grazing (volatilization 7.5 % of the N-excretion), 4 kg during application of slurry on grassland (5 % of the ammonia-N), 0 kg after application on arable land (1.25 % of the ammonia-N) and 14 kg from the stable (7 % of the N-excretion), which was therefore the main source of ammonia.

Table 5 Nutrient flows of the manure component for the average farm in the middle of the eighties, the prognoses at the start of 'De Marke' and the values realized in the financial years 1993/1994 and 1994/1995 (kg/ha)

Characteristic	'average' 1983/86		'De Marke' prognoses		1993/94		1994/95	
	N	P	N	P	N	P	N	P
Input:								
- production faeces and urine at pasture	191	26.0	55	7.0	52	7.7	62	3.3
- production faeces and urine indoors	224	32.0	151	20.2	209	24.7	194	27.1
Output:								
- faeces + urine at pasture (after volatilization)	164	26.0	51	7.0	48	7.7	57	3.3
- applied slurry (after volatilization)	146	32.0	137	20.2	181	25.8	227	33.5
- mutation manure in storage	0	0.0	0	0.0	11	-1.0	-50	-6.4
Input - Output (= ammonia from manure)	105	0.0	18	0.0	21	-0.1	22	0.0

6.4. The soil/crop component

Although the quantities of N in faeces and urine at 'De Marke' were considerably lower than at the current farm, the amount of N in slurry - after subtraction of ammonia volatilization - was higher. This is due to the strong reduction in the proportion of manure excreted at pasture and to the emission-reducing measures for slurry. In both years slurry was the main source of nutrients at 'De Marke' (Table 6).

In the financial year 1993/1994 (including the growing season 1993), the total nutrient supply to the soil was similar to the prediction (355 kg N and 37.2 kg P/ha). In 1994/1995 the supply was substantially higher, because more slurry and fertilizer were applied on grassland as a result of a change in the method of calculating the fertilizer requirements. Moreover, the correction for lower yields due to drought was insufficient. Therefore, the store of slurry decreased in the financial year 1994/95. The method to calculate fertilizer requirements has been adapted again and it may be expected that in the coming financial years the supply will be similar to the prediction again. The contribution of clover to the N-supply of the farm was lower than expected, because the clover was damaged during winter in most years.

Table 6 Nutrient flows of the soil/crop component of an average farm in the middle of the eighties, the prognoses at the start of 'De Marke' and the realized values in the financial years 1993/1994 and 1994/1995 (kg/ha)

Characteristic	'average' 1983/86		'De Marke' prognoses		'De Marke' 1993/94		'De Marke' 1994/95	
	N	P	N	P	N	P	N	P
Input:								
- faeces and urine at pasture (after volatilization)	164	26.0	51	7.0	48	7.7	57	3.3
- slurry application (after volatilization)	146	32.0	137	20.2	181	25.8	227	33.5
- inorganic fertilizer	330	15.0	67	6.0	52	1.8	96	0
- deposition	49	1.0	49	0.9	49	0.9	49	0.9
- N-fixation clover	0	-	30	-	12	-	5	-
- harvest loss	60	6.0	21	3.1	18	2.5	20	2.6
Output:								
- harvestable crop	398	48.0	276	37.3	275	35.2	270	34.5
Input - Output *	351	32.0	79	-0.1	85	3.5	184	5.8

* = denitrification, nitrate leaching and accumulation

The quantities of N and P in the harvestable crop (gross yield) were in both years almost equal to the predictions, but considerably lower than those in practice. The relatively much higher nitrogen production at the current farm - 398 kg N/ha versus, on average, 276 at 'De Marke' - is the result of a combination of a higher proportion of grassland and a higher fertilizer level at the grassland. On average during the two financial years, 135 kg N and 4.7 kg P per ha of the supplied nutrients were not recovered in the harvested products. These quantities must thus have accumulated in the soil, leached, eroded, or denitrified (only N). Modifications in the soil store can only be identified in the long run, because of its large size: the upper 30 cm of the soil at 'De Marke' contain on average more than 7,000 kg of N and more than 3,100 kg of P per ha.

6.5. The feed component

The proportion of the nutrients in harvestable crop and purchased feed consumed by the animals was in accordance with the predictions and therefore substantially higher than at the current farm. Hence, nutrients in feed are being used more efficiently. This is mainly the result of lower grazing losses - due to short grazing periods per plot, stabulation at night and a short grazing season - fast and skilful silage making, and harvesting of maize straw and beet leaves, products that at the current farm are left in the field. The inputs of N and P with feed from outside the farm and from the feed stocks were substantially higher than predicted, because of a larger herd size. Moreover, more N and P was imported with feed than necessary according to the feeding standards. Fodder with 'adapted' nutrient contents is rather expensive and it is cheaper to limit the input of N and P on the farm through restricted fertilizer purchases. Differences between years in the balance of inputs and outputs are partly due to inaccuracies in determining the feed stocks.

Table 7 Nutrient flows for the feed component for an average farm in the middle of the eighties, the prognoses at the start of 'De Marke' and the values realized in the financial years 1993/1994 and 1994/1995 (kg/ha)

Characteristic	'average' 1983/86		De Marke					
			prognoses		1993/94		1994/95	
	N	P	N	P	N	P	N	P
Input:								
- harvestable crop	398	48.0	276	37.3	275	35.2	270	34.5
- purchased feed	182	32.0	41	5.9	82	15.0	84	11.5
Output:								
- feed intake	496	74.0	278	40.1	336	47.1	330	43.8
- feed sold	0	0.0	0	0.0	8	1.2	0	0.0
- mutation feed stock	0	0.0	0	0.0	-35	-2.3	17	0.8
Input - Output*	84	6.0	39.0	3.1	48	4.2	7	1.4

* grazing, harvesting, conservation and feeding losses

7. The fate of the nutrient surplus

7.1. Nitrogen

The nitrogen surplus of the farm (Table 3) - in 1993/94 and 1994/95 140 and 198 kg N/ha, respectively - is the sum of ammonia volatilization, denitrification, run-off and leaching and modifications in the soil store. Run-off is negligible, as there is hardly any surface water at 'De Marke'. Only at extremely very high rainfall, water will be removed through ditches. As indicated in Section 6.2, about 22 kg of N was lost as ammonia from manure. According to the calculations, 2 kg of ammonia-N/ha was lost from crop residues. Loss of ammonia from silage is not known. Total loss of ammonia-N thus amounts to 24 kg plus an unknown quantity from ensiled products.

Through denitrification - a process in which nitrate is transformed into elementary nitrogen and nitrogen-oxides - a maximum of some dozens of kg N/ha were lost annually from the top soil (Corré, 1996). Denitrification can be an important process in parts of the plots where water stagnates (lack of oxygen) and there is ample supply of easily decomposable organic matter. Also in deeper layers denitrification can take place, but that is considered relatively unimportant at 'De Marke' because of the deep groundwater level, the low contents of organic matter in the subsoil and the limited amount of nitrate that leaches from the top soil. It has been assumed that during both financial years denitrification was 25 kg N/ha.

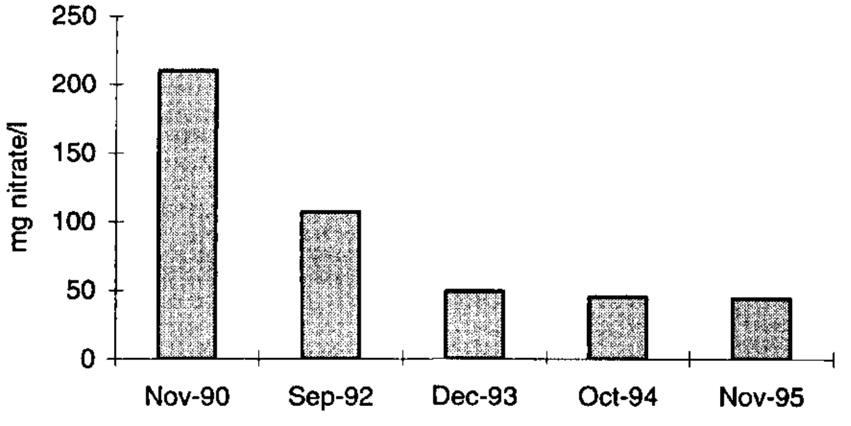

Figure 1. The concentration of nitrate in the upper groundwater of 'De Marke'

In Figure 1 the time course of average nitrate content in the upper groundwater is given, as measured by RIVM (National Institute of Public Health and Enviromental Protection). The nitrate contents strongly decreased and were since December 1993 even slightly below the level of 50 mg nitrate/l. Hence, the nitrate content of the groundwater of 'De Marke' meets the requirement for drinking water, a strict objective of the farm. Research of De Waterleiding Maatschappij (Waterworks) Oostelijk Gelderland in the autumn of 1993, showed nitrate contents under current plots close to 'De Marke' almost four times as high. It is striking that the adapted management seems to have resulted in realization of the objective 'clean groundwater' within a few years. The expectation was that it would take much longer to meet the nitrate norm, especially under those plots that had received large amounts of manure in the recent past, certainly when those plots continued to be fertilized (Goossensen & Meeuwissen, 1990). Such plots, characterized by large amounts of phosphorus and heavy metals in the soil, form part of 'De Marke'. However, also the groundwater under these plots met the 50 mg-norm. No clear differences were found among crops. Also irrigation did not have a clear influence. The measurements represent instantaneous indications of the nitrate contents of the groundwater and another moment of sampling might have given a different result. It is therefore not possible to quantify nitrate leaching accurately. On the basis of precipitation surplus and the measured nitrate contents in the groundwater, annual leaching is estimated at 50 kg N/ha.

The sum of ammonia-N (except that from silage), denitrification and leaching of nitrate amounts to 99 kg N/ha. The average surplus on the balance at farm level is 169 kg N/ha. The difference between these two values (70 kg N/ha) must be attributed to measuring errors, losses from ensiled feed and changes in the store of soil organic-N. On average, the store of soil organic-N appeared to have increased annually by 17 kg/ha between 1990 and 1995, but that number - in both years based on the analysis of 1 soil sample per ha - is not very reliable statistically.

At 'De Marke' large differences in net mineralization were found among plots and among years. Generally, the results suggest that the more humid the conditions during the growing season, the higher nitrogen mineralization from the soil organic N store. In the wet year 1993, mineralization was on average 90 kg N/ha higher than in the dry year 1994 (Aarts, 1996). This could imply, that - if the soil store is in equilibrium in the long run - it decreases in relatively wet years and increases during dry years. On the farm balance the term 'change in soil store' is not included in the calculations. In dry years the surplus may, therefore be considerably higher without negative impacts on the environment.

7.2. Phosphorus

The P-content in the upper groundwater was only 0.13 mg/l when sampled in October 1994. This is much lower than the target value for sandy soil (0.4 mg/l; Willems & Fraters, 1995). As hardly any P leached, it is most likely that the P-surplus accumulated in the soil. However, despite a slightly positive P-surplus, the P-status of the soil (PAl- and Pw-value) decreased by some 4 % annually, which - in combination with low P-fertilizer levels - caused problems in a number of plots during early growth of maize (Aarts, 1995). Soil analyses indicate that the solubility of P has decreased, especially where the soil contained high concentrations of iron and aluminum (Schoumans, 1996). Until now, the lower P-status of the soil and the associated slower early growth of maize have not resulted in lower yields. However, problems did occur in weed control and in proper timing of sowing Italian ryegrass between the rows of maize (catch crop).

8. Discussion and conclusions

The results obtained sofar suggest that on dry sandy soils, strict environmental standards for losses of nitrogen and accumulation of phosphorus can be attained within a short time, while maintaining the current milk quota. The nutrient flows realized within the farming system appeared to agree well with the values calculated on the basis of existing knowledge. Intake of N and P by cattle was, however, higher than expected, as the N- and P-contents in the ration were too high (above the feeding standards), and the number of young stock higher than expected. Nevertheless, the input of N and P in purchased feed could be reduced by 50 % compared to that of the average farm in the middle of the eighties. As the intake of N and P in feed was higher than expected, excretion in faeces and urine was also higher. This did not lead to problems with respect to the application of manure on the farm, but the (calculated) ammonia emission was higher than expected (mainly from the stable). However, ammonia emission was still below the official norm (a reduction of 70 % compared to 1980). To compensate the relatively high input of N and P in purchased feed, the input of artificial fertilizers had to be limited. From the spring of 1994 onwards 'De Marke' is therefore not using P fertilizer any longer.

Grass, maize and fodder beets could be grown in such a way that the strict environmental norms for nitrate losses could be met. Due to a better utilization of animal manure and lower fertilization levels the use of fertilizer-N could be reduced by 74 % compared to current practice. The nitrate concentration in the upper groundwater decreased within a few years by 75 % until just below the standard of 50 mg nitrate/l, with only small differences among crops. After breaking up three-year old grassland, fodder beets as well as maize appeared to be able to absorb the nitrogen released from the decomposing sod. Hence, that allows in principle introduction of a ley farming system comprising only maize and grass. This is an important point, as it appeared impossible to utilize the yield of the area of fodder beets (10 % of the farm area) in a satisfactory way in the ration. The area of fodder beets will therefore be reduced.

The contribution of clover to the nitrogen supply of grassland was smaller than expected as a result of winter (frost) damage to the clover seedlings after sowing in autumn. Clover without frost damage could be easily maintained in the sward. Shifting the moment of sowing to the spring, might allow further savings on fertilizer-nitrogen in the future.

When calculating the annual nitrogen surplus of the farm, in principle the change in soil store would have to be taken into account.However, annual changes can not be measured accurately enough, because of the large quantities involved. When calculating the (average) surplus over a longer period, the change in soil store can be included. Indications suggest that the rate of change in the soil store strongly depends on moisture supply (Hassink et al., 1996). Under more favourable soil moisture conditions, the rate of decomposition of the organic material is apparently higher, resulting in a higher rate of mineralization. When the change in soil nitrogen store is not considered, a high nitrogen surplus in a dry year can be less damaging to the environment than a lower surplus in a wet year. The experimental period is still too short for estimation of the influence of the farming system on the 'equilibrium-level' of the soil organic nitrogen store. That value is, however, important in determining the environmental impact of the farm surplus over a longer time period.
It appeared possible to more or less balance the input of P in fodder and the output in milk and meat. The P-surplus at the farm was only 18 % of that on the current farm. Phosphorus availability for the crop decreased, because of that low P-surplus. Therefore, problems appeared during early growth of maize in a number of plots. These problems may be limited in the future by applying slurry after ploughing, preferably in the crop rows, to facilitate access of the plant roots to the P in the slurry. Appropriate machinery for this practice is under development.

To obtain reliable results the research must be continued for a much longer period of time, because the system has to stabilize, the soil nutrient and organic matter stores and soil fertility react slowly to changes and weather conditions are always variable. However, there are no reasons to expect major problems in the near future.

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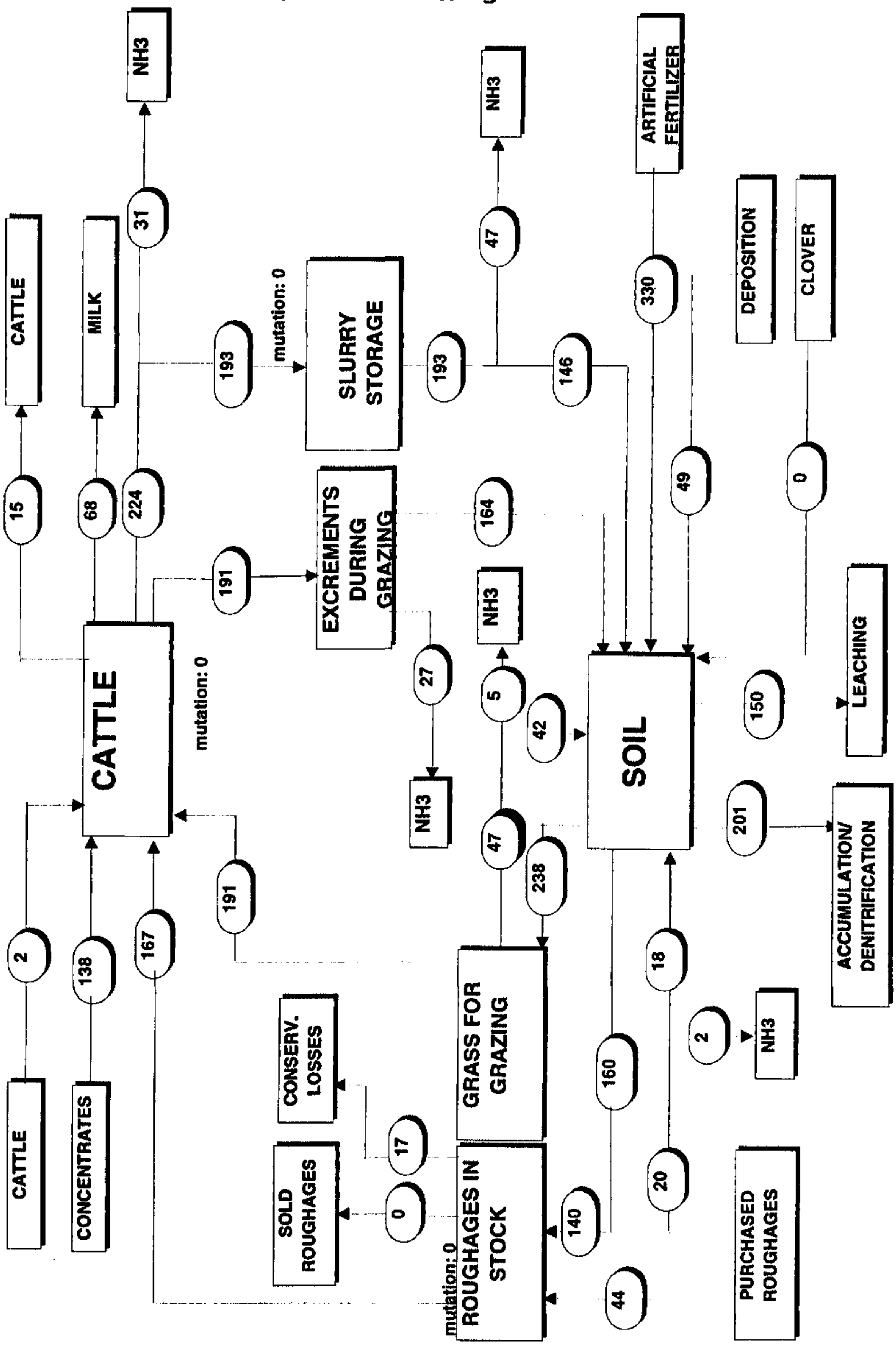
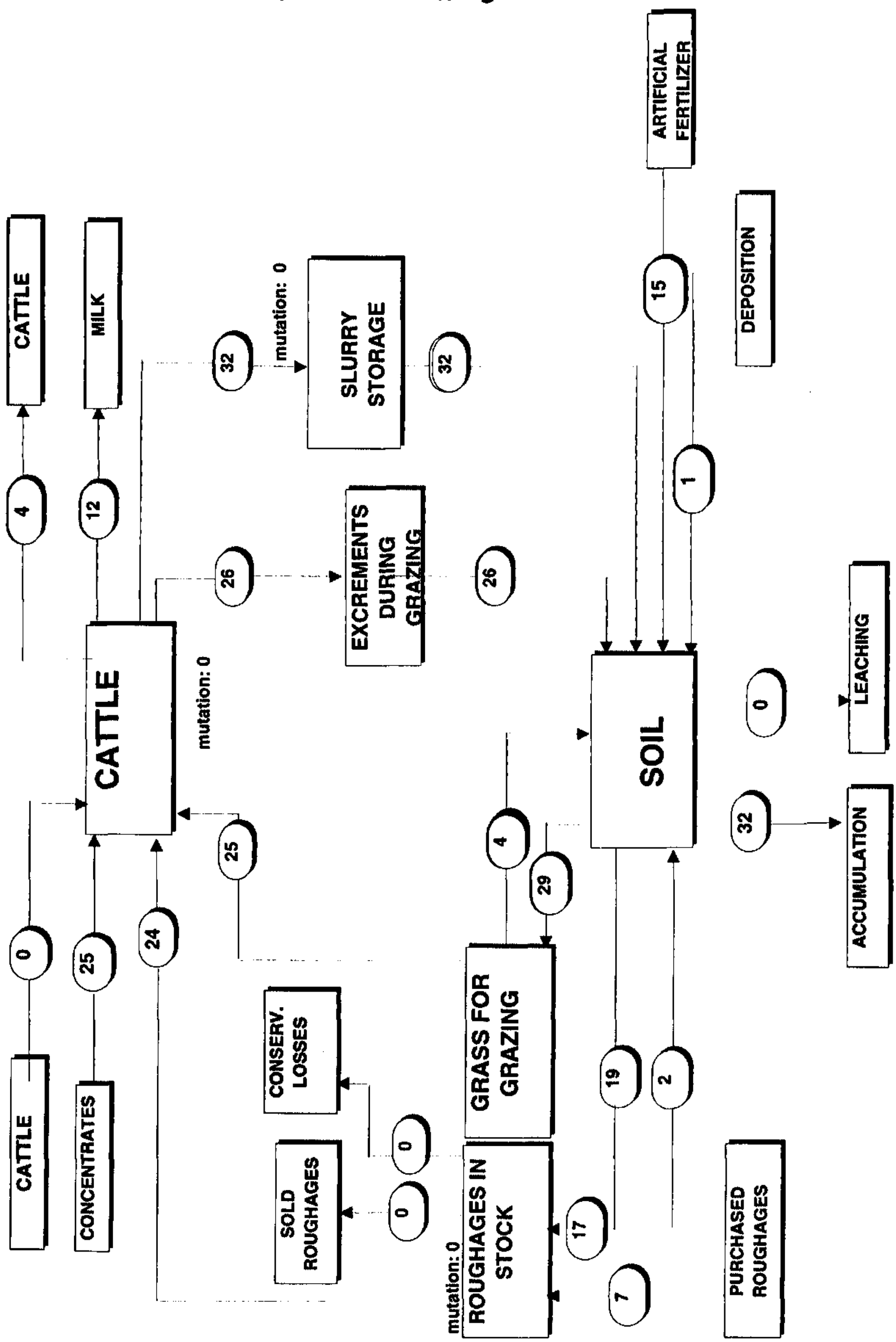
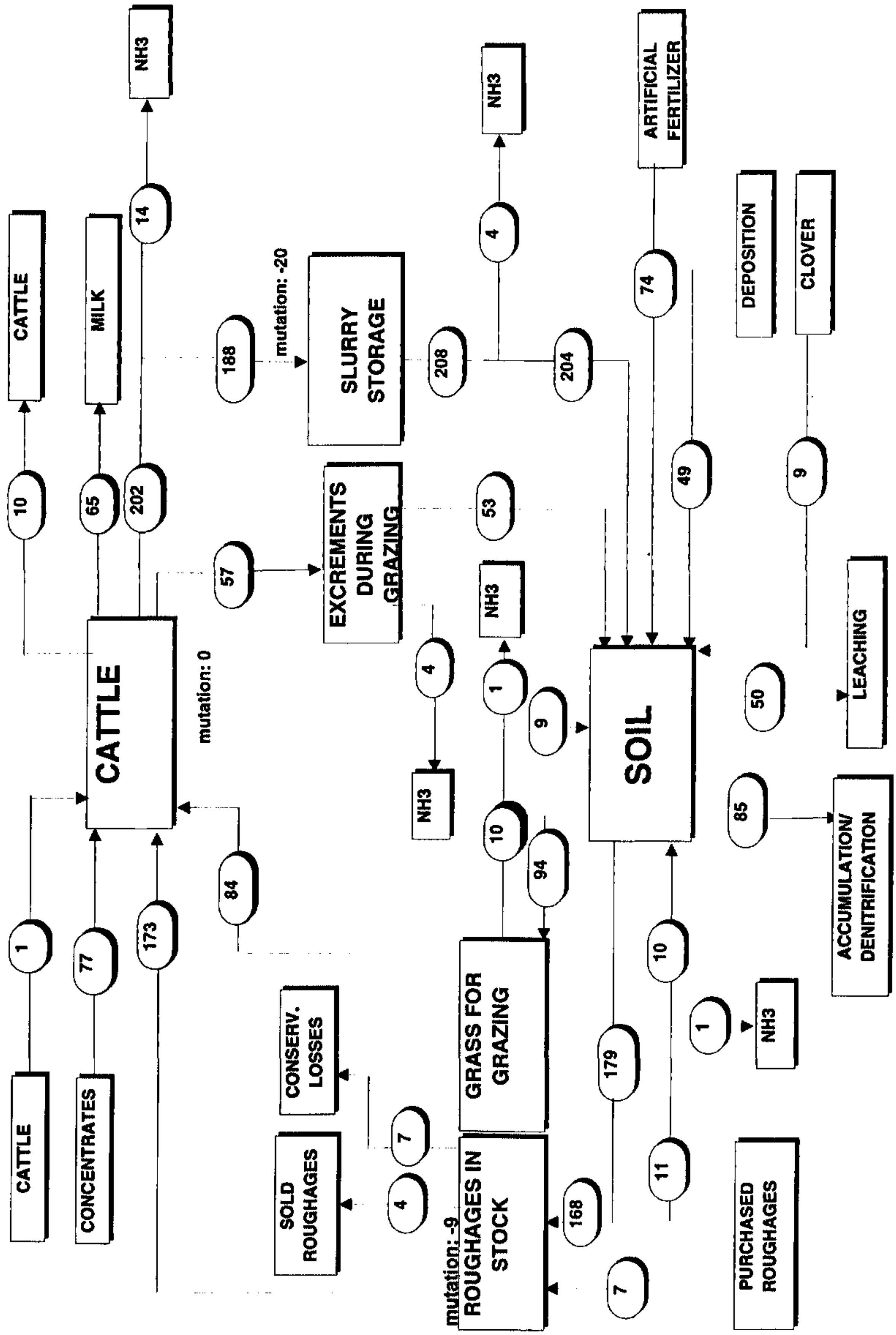
Appendix I: Nitrogen flows of a conventional diary farm (1983 - 1986), kg/ha



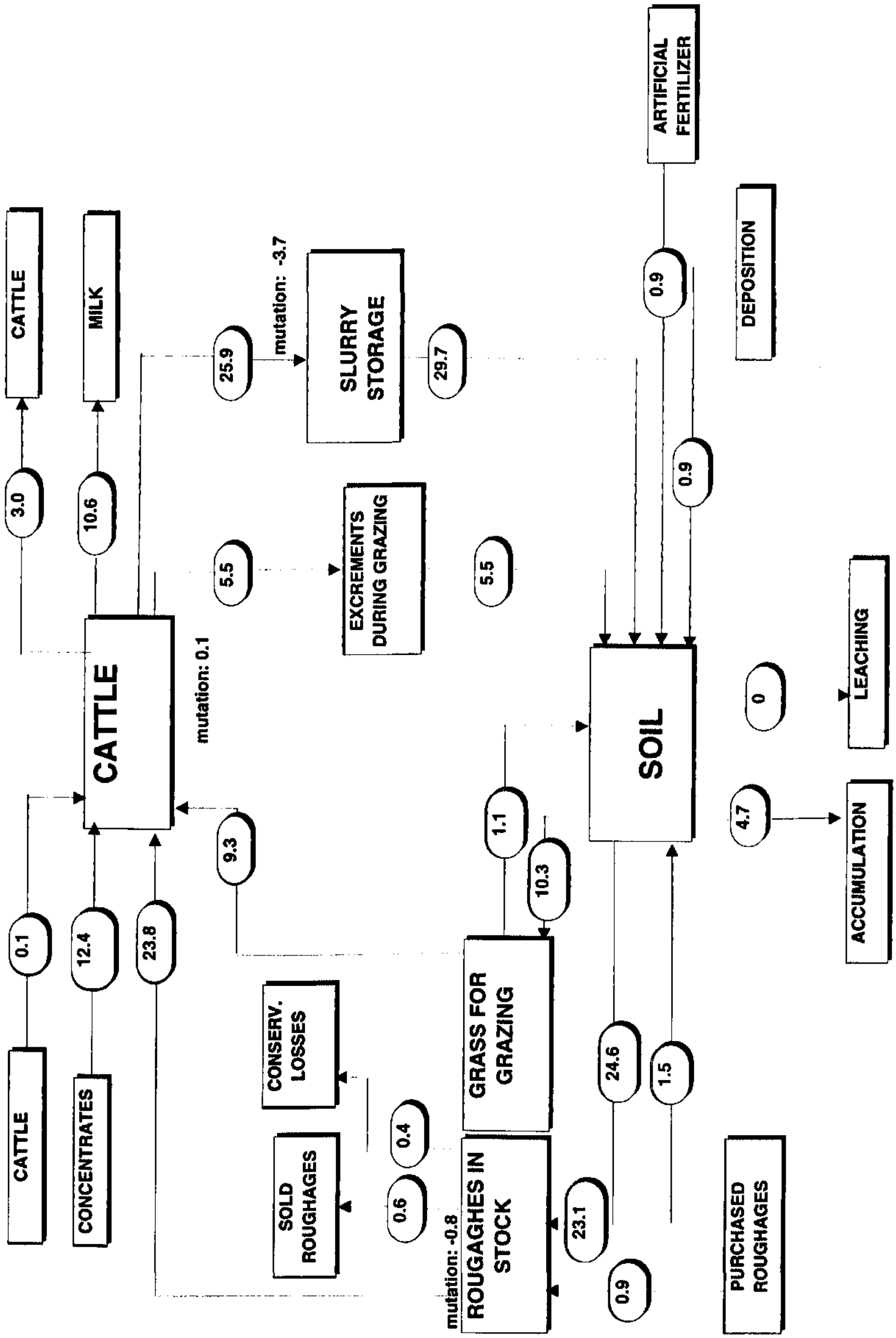
Appendix II: Phosphorus flows of a conventional dairy farm (1983 - 1986), kg/ha



Appendix III: Nitrogen flows of 'De Marke' (1993 - 1995), kg/ha



Appendix IV: Phosphorus flows of 'De Marke' (1993 - 1995), kg/ha



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