6 The Nutrient Management Project of the VEL and VANLA Environmental Co-operatives

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6.1 Introduction to the nutrient management project

This chapter describes the on-farm nutrient management project of the VEL and VANLA environmental co-operatives (see also Stuiver and Wiskerke, this volume). Figure 1 provides a schematic overview of the development of the project, which has its roots in a heterogeneous set of farming practices (A in Figure 1) that already existed in the area. Throughout the 80s and 90s, farmers in the area were subject to a newly emerging set of regulations (B in Figure 1). The effects of these were twofold: on the one hand several regulations were at odds with the practices employed on the small-scale farms in the area (sometimes prohibiting them outright); on the other hand farmers became increasingly interested in the particularities of their own ways of farming.

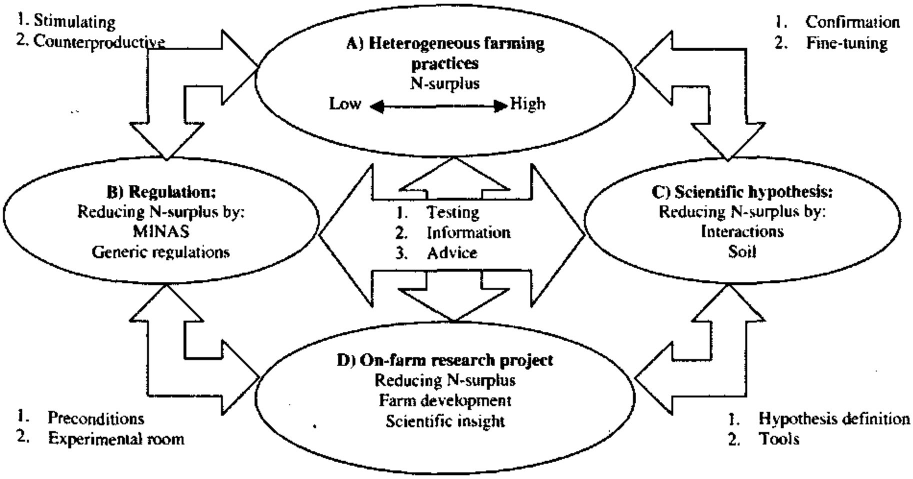


Figure 1 Schematic overview of the relation beween farming practices, a scientific hypothesis, environmental regulation and the on-farm research project at the start of the nutrient management project of the VEL and VANLA environmental co-operatives.

An initial analysis of the nitrogen flows of 93 farms in the area showed a large variation in nitrogen surpluses between farms (see textbox 1). A number of farms appeared to combine very low N surpluses with high production levels. These farms showed a surprisingly high N efficiency: they became (if they were not already) interesting examples for other farmers in the area. This analysis, widely discussed by local farmers, was subsequently enriched with local insights concerning the most promising practices encountered within the area. According to farmers, differences in efficiency between farms were related to the presence (or absence) of what they referred to as a 'particular balance within the farm' (see Hoeksma's story in van der Ploeg 2003).

Textbox 1 A first analysis of nitrogen balances in the VEL and VANLA project

At the outset of the project (between May 1st 1995 and April 30th 1996) the nitrogen balances of 93 VEL and VANLA dairy farms were analysed (Verhoeven *et al.* 1998). The NEL content (net energy lactation, MJ.ha^{-1}) of the feed was computed (according to van Bruchem *et al.* 1999) in order to estimate the amount of N (kg.ha^{-1}) in the fodder produced on the farm. The NEL requirements of the herd, including dry cattle and young stock were subtracted from the amount of NEL in purchased feed. (These requirements were multiplied by a factor of 1.1, following observations in practice and in agreement with findings of Kebreab *et al.* 2003). For each farm calculations were made of the amount of N in the feed produced on the farm and of the NEL/N ratio met by on-farm production of fresh grass and grass silage. The N content of the manure was calculated as a function of the N produced in imported feed and feed produced on the farm minus the N in milk and meat.

The outcomes revealed a considerable diversity (see Table 1.1). Output of N on the farms ranged from 31 to 93 kg N ha^{-1}, with an average of 63 kg N ha^{-1} (equivalent to approximately 11,500 kg milk ha^{-1}). Some farms already used relatively little inorganic fertiliser (154 kg N ha^{-1}) while others exceeded 400 kg ha^{-1}. The average dose was 292 kg N ha^{-1}. The amount of N imported in concentrates ranged from 31 to 197 kg N ha^{-1}, with an average of 97 kg N ha^{-1}. The (calculated) N surpluses ranged from 162 to 560 kg N ha^{-1}. This means that, in 1996, there were some farms that already met the 2003 target, whereas others would have to reduce their surplus by almost 400 kg ha^{-1}. The average N surplus on the participating farms was 326 kg N ha^{-1}, compared to an average surplus for farms in the Northern provinces of about 350 kg N ha^{-1}. The apparent N efficiency of animals ranged from 8 to 24 per cent, with an average of 17 per cent. The calculated apparent N efficiency of the soil ranged from 33 to 78 per cent with an average of 46 per cent. At farm level overall apparent N efficiencies ranged from 10 to 28 per cent with an average of 16 per cent.

Table 1.1 N flows and efficiencies in VEL and VANLA farms (n = 93) from 1 May 1995 to 30 April 1996

	Minimum	*Mean*	*Maximum*
N flow (kg N ha^{-1})			
Products (milk and meat)	31	63	93
Concentrates	31	97	197
Fertilizer	154	292	478
Home-grown feed	182	280	434
Manure	195	314	533
Surplus	162	326	560
Apparent N efficiency (%)			
Animal level ^{A}	8	17	24
Soil level ^{B}	33	46	78
Farm level ^{C}	10	16	28

^{A} Calculated as product over concentrates plus home-grown feed; ^{B} Calculated as home-grown feed over fertiliser plus manure; ^{C} Calculated as product over fertiliser plus concentrates.

The differences between farms in apparent N efficiency and N flows started a considerable debate in the two co-operatives about the relationships between productivity and the use of inputs. Some of these relationships are shown in Table 1.2. It was discovered that the average dry matter yield per ha per farm was not related to the use of fertiliser and that the N surplus was not related to the amount of milk produced per cow. However, the amount of N produced per ha was strongly related to the amount of concentrates imported. The more intensive the farm, the more N was imported.

Table 1.2 Generic relationships derived from first regional appraisal.

$$\text{Dry Matter Yield (kg.ha}^{-1}\text{)} = 7618 + 4.15\ (1.91)^{*} * \text{N fertilizer (kg.ha}^{-1}\text{)};\ R^2 = 0.049$$

$$\text{N surplus (kg.ha}^{-1}\text{)} = 165 + 24.1\ (7.87)^{**} * \text{Milk Yield (Mg.yr}^{-1}\text{)};\ R^2 = 0.094$$

$$\text{N product (kg.ha}^{-1}\text{)} = 28.3 + 0.281\ (0.026)^{***} * \text{N concentrates (kg.ha}^{-1}\text{)} + 0.024\ (0.012)^{*} * \text{N fertilizer (kg.ha}^{-1}\text{)};\ R^2 = 0.632$$

Generic relationships were derived from (multiple) regression analyses. Standard error of the mean in parentheses. $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$.

Although the term was not yet used, the promising practices of these farms were understood as 'novelties' (see introductory chapter of this book) that is, as practices that potentially contained solutions that could be applied to other situations. In this way a 'programmatic approach' emerged in which all the subsystems of the farm were considered potentially relevant in the search for sustainability. Subsequently, re-balancing became an increasingly central and self-evident notion: the manure, the soils, the grassland management, the feeding strategies, the quality and composition of the milk could all be changed individually and be recombined in new ways that would result in more acceptable outcomes.

At that time, the scientists (C in Figure 1) who had performed the analysis (described in Textbox 1) had developed the hypothesis that optimising the 'animal' subsystem might prove counterproductive in reducing nitrogen surpluses, as this might induce negative effects at the system level (Van Bruchem *et al.* 1999). Rather, a combination of different elements of scientific knowledge with farmers' insights, led to the formulation and subsequently instigation of a programme with a more specific focus on sustainable and locally appropriate solutions. In contrast to the, then emerging, national agro-environmental policy, (which was technologically oriented) this programme focused on changes in management style. It was adapted to local conditions (e.g. the small-scale landscape) and oriented towards an overall re-balancing and downgrading, rather than a partial downgrading (see introductory chapter of this book).

The benefits of this approach were quite obvious. Scientists wanted to test their theoretical framework in practice and farmers felt the need to make their practices more explicit, more understandable and more defendable. The programme was, admittedly, a hybrid – especially in the beginning. Although reference could be made to specific scientific insights (as will be shown throughout this chapter), these were segmented, isolated, not tested on a broader scale and, as yet, not combined. The VEL and VANLA nutrient management project can be considered as a first attempt to a) systematically combine local and (new) scientific insights and b) put them into practice, monitor and, if needed, adapt them. An agreement with the Minister of Agriculture permitted the creation of a niche (or 'field laboratory': see Stuiver *et al* in this volume; and D in Figure 1) in which the programme could be set up.

In this chapter we will discuss both the theoretical background and practical outcomes of this research project. Section 6.2 provides a short introduction on the problem of nitrogen surpluses in Dutch dairy farming. Section 6.3 deals with some crucial theoretical elements that informed this research project. Section 6.4 describes the way these elements were moulded into the nutrient management project. Section 6.5 highlights the theoretical background of one important and characteristic element of the nutrient management project, the typical feeding strategy. Section 6.6 provides a summary of the technical results of the project and Section 6.7 concludes by examining the broader impact of the project.

6.2 Nitrogen surpluses in Dutch dairy farming

Dairy farming in Western Europe is mainly characterised by highly productive farming systems. High production levels are highly dependent on high external inputs of nutrients, mainly from fertiliser and concentrates (Oomen *et al.* 1998). These not only lead to high production but also to excessive emissions of nutrients to the environment. An analysis of the nutrient flows in Dutch agriculture revealed that dairy farming is the primary source of nitrogenous emissions, whereas the phosphorus surplus can primarily be attributed to pig and poultry production (van Bruchem and Tamminga 1997). According to van Keulen *et al.* (1996), nitrogen emissions from the milk and meat sectors rose from 36 to 83 million kilograms between 1950 and 1985. This was due to an increase in nitrogen inputs in concentrate from 8 to 153 million kilograms (almost a twenty fold increase) and in chemical fertiliser from 70 to 379 million kilograms, (more than a five-fold increase). Thus throughout this period the nitrogen use efficiency[1] (NUE) of Dutch dairy farming decreased by a factor of about 3, from approximately 45 per cent in the 1950's to only 15 per cent in the 1980s. From this data, we can calculate the marginal nitrogen use efficiencies to be around 20 per cent and 5 per cent for concentrates and fertiliser respectively. These low rates of efficiency are the cause of nutrient imbalances and the emission of excess nutrients from farms to ground and surface water and the atmosphere, all of which have adverse environmental impacts (see Jarvis *et al.* 1995).

From 1985 onwards the problem of nitrogen surpluses became recognised in both scientific and political circles and since this time the Dutch government has introduced a gradual tightening of policies to reduce nutrient surpluses (Oenema *et al.* 1998). Between 1986 and 1996, and probably as a consequence of these measures, the nitrogen surplus (inputs-outputs) of Dutch agricultural land decreased, but only by 14 per cent, from 618 to 535 million kilograms N (Oenema *et al.* 1998). In 1998, the government introduced the Mineral Accounting System (MINAS), an obligatory system under which farmers have to account for the inputs and outputs of nutrients and calculate the surpluses on an annual basis (see van den Brandt and Smit 1998, for a full description). The aim of the policy was to create enforceable and realistic measures that would comply with the EU Nitrate Directive (European Community 1991)[2].

From the late eighties onwards, much technical research, aimed at improving nitrogen efficiency in dairy farming has been carried out. Examples include the development of; low-emission housing systems (reviewed by Monteny 2001), manure application methods (van der Meer *et al.* 1987), feed protein evaluation systems (Tamminga *et al.* 1994) and improved recommendations for fertilisation (Oenema *et al.* 1992). This research has led to the development of new tools to reduce nitrogen surpluses in specific farming subsystems. At the same time possibilities for reducing nitrogen surpluses at the level of the whole farming system also became the focus of study. One example is the prototype experimental farm 'De Marke' (Aarts 2000) whose work, from 1992 onwards, has shown that it is technically feasible to combine high production levels with low nitrogen surpluses, although with some increase in production costs.

By the late nineties, there were several examples of farms that had achieved low levels of nitrogen surpluses, while maintaining high production levels per hectare. The 'Cows and Opportunities' project, which involved 17 farms (Oenema *et al.* 2001) showed a variation in nitrogen surpluses of between 47-349 kg $ha^{-1,}$ with an average of 207 kg (1997/1998 data). In the 'Farmers Data', project 91 dairy farms, scattered across the country succeeded in decreasing their nitrogen surplus from an average 237 kg ha^{-1} in 1997 to 153 kg ha^{-1} in 2002 (Doornewaard 2002). These projects show that the combination of high production levels and low nitrogen surpluses is not only technically feasible but can also be realised on commercial dairy farms. However, the average nitrogen surplus in the Netherlands remains high. In 1997, average nitrogen surpluses for specific groups of dairy farms in the Netherlands ranged from 220 to 440 kg N/ha, with an average of 308 kg N/ha^{-1} (including animal correction: Reijneveld *et al.* 2000). The average MINAS nitrogen surplus of a sample of dairy farms [3] in Friesland was 325 kg ha^{-1} in 1997 (Anon. 1999). Increased pressure from the European Community, led the Dutch government to shorten the target period for reducing surpluses, from 2008 to 2003 (Henkens and van Keulen 2001). As a consequence, since 2003 farms have had to meet targets for nitrogen surpluses of 100 and 180 kg per hectare for arable land and grassland respectively. This implied the need for farmers to achieve an average reduction of approximately 150 kilograms nitrogen per hectare between 1997 and 2003, with some farmers having to reduce their surplus by as much as 300 kilograms of nitrogen per ha. Despite the efforts of the scientific community and of policy makers, the task of meeting these targets was (and remains) an enormous challenge and is compounded by the tendency of these approaches to increase costs (Aarts 2000). In the next section we focus on a number of crucial theoretical elements, surrounding the VEL and VANLA nutrient management project which, in our opinion, show the potential for meeting this challenge in a cost-effective way.

6.3 Crucial elements of the nutrient management project

Technology in society

The farmers in the VEL and VANLA area developed a proactive attitude towards the reduction of nutrient surpluses. In 1992, they were among the first farmers in the Netherlands to document the inputs and outputs of nutrients on their farms (Anon 1994). However, these farmers found that several of the technologies being proposed (or imposed) as ways to improve nitrogen efficiency seemed inappropriate or counterproductive. Legislation requiring the injection of slurry into the soil was a prime example of this. The rationale behind this legislation was that injection reduces emissions of ammonia and increases the efficiency of use of N significantly in comparison with surface application (van der Meer *et al.* 1987). However, farmers in the VEL and VANLA region were concerned that injection of slurry into the soil would damage the topsoil and soil life and the heavy machinery would cause soil compaction, adversely affecting the sward quality and productive capacity of their permanent grasslands. Furthermore, the size of the machinery was inappropriate for the small fields in the area and, as injection was mostly done by contract-workers this would increase the costs of manure application, conflicting with the economical farming style of most farmers in the area, (van der Ploeg 2000). As a result, farmers considered injection of slurry as a threat to their production system rather than a tool to improve N efficiency.

This example illustrates that the success or acceptability of a single technology not only depends on its technical capacity but also on its effects on the entire production system, its environment and specific local conditions. A technology can never be isolated from its surrounding environment. Innovation, adoption and adaptation are all embedded in socio-technical regimes and overall socio-technical landscape. In this respect a promising technology or novelty (see introductory chapter) needs to be evaluated from a technology-in-society perspective (Rip and Kemp 1998). This perspective focuses on the interaction between technology and society and stresses the processes of co-evolution between technological innovations and social context.

System approach

The efficiency of nutrient use in Dutch agriculture significantly decreased from 1950 onwards, due to easy and cheap access to external inputs and management strategies based on the rationale of maximising short-term financial profits. The longer-term impacts of such strategies are indicated in Textbox 2. Relating these more generalised concerns to the level of the individual farm unit, requires the adoption of new integrative methodologies. (Waltner-Toews 1997). For example, flows of nutrients within a dairy farm, can be usefully understood by describing the farm as a single system, subdivided into four subsystems: soil, feed, animals and manure. This type of system approach is often used when seeking to reduce nitrogen surpluses at the farm level (e.g. Jarvis *et al.* 1995; Aarts 2000) and provides the basis for the current legislation (MINAS). A system approach makes it explicit that all subsystems are interrelated and changes in one part of the system affect the other components of the system. When production systems become unbalanced the efficiencies can decrease, due to negative interactions between the subsystems. On the other hand, in more balanced situations, mutually beneficial effects can arise and the performance of the production system as a whole may surpass the total of the subsystems (Schiere and Grasman 1997). To optimise the outcomes of the whole system it is important to seek to improve the coherence, or positive interactions, among the subsystems, rather than aim to maximise the performance of the subsystems in isolation.

Textbox 2 Theoretical optimization of external input level

Increasing inputs of fertiliser and concentrates can increase the outputs of agro-ecosystems. Figure A (below) shows a typical dose-response curve for this relationship. Initially the response-line is concave and the relationship is one of increasing returns (I in Figure 1A below). However, at external input levels beyond 100, the output curves become convex, and enter the domain of decreasing returns (II) and, eventually, domain III – that of decreasing yields and/or increasing problems/costs. In domain I, nutrient losses to the environment (Figure B) appear to be negative, with the system responding positively to management measures. In domain II efficiency decreases and losses to the environment increase, while in domain III the nutrient losses become extremely high. This stage represents economic activities with ecologically damaging side-effects, which ultimately become economically unsustainable.

In terms of production efficiency the optimum level of external inputs is the point at which the production curve changes from concave to convex. This optimum level should be used as the target for developing efficient production systems in all subsystems. We argue that this point is also where the probability of higher order positive interactions between subsystems is highest, resulting in a system output that exceeds the level of the mono-factorial dose-response outputs.

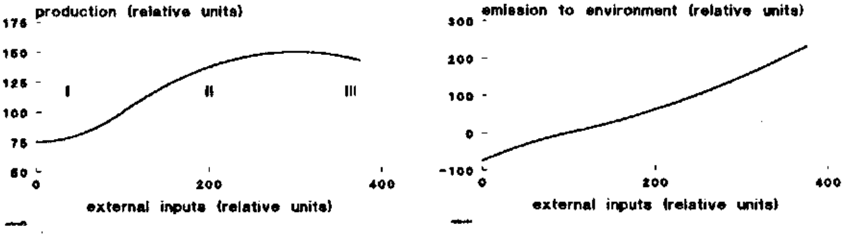


Figure 2.1. Output (production) and losses to the environment, relative to the external inputs: I, domain increasing returns; II, domain decreasing returns; III, domain decreasing yields (van Bruchem, unpublished).

The level of milk production per cow provides an instructive example of this principle. In terms of the individual cow a high level of milk production is more efficient, as proportionately less nutrients are required for its maintenance. However, if the roughage produced on the farm does not provide enough nutrients to reach this high production level, external feed (e.g. concentrates) will be required. This implies a decrease of the production efficiency at the whole farm level, due to an imbalance (negative interaction) between the availability of roughage and the milk production level per cow.

Downgrading and re-balancing

The system approach provides one way to describe and understand a phenomenon that the VEL and VANLA farmers recognised as crucial, namely the creation of 'a particular balance within the farm'. Farming can also be described as 'the art of fine tuning'. Resources such as fields, cattle, crops, manure need to be unravelled and re-moulded in order to create combinations that are as productive and sustainable as possible and this unravelling and remoulding requires fine-tuning[4] (Groen *et al.* 1993; Portela 1994; Bouma 1997; van der Ploeg 2003). With increasing insights (i.e. with developing local and/or scientific knowledge), and through adjusting individual growth factors (of whatever type), the whole is constantly being re-balanced. Hence, step-by-step improvements are created. Both these theories imply that a new optimal equilibrium in the dairy farming system requires a fundamental shift in management style from one of up-scaling and the management of single-factors, to downgrading and the implementation of multi-factor strategies.

Downgrading implies a reduction in the use of some growth factors in order to create a new balance that allows farming to be both ecologically and economically sustainable (see introductory chapter of this book). When this downgrading is well articulated it can result in an improved income, as a result of immediate savings (on fertiliser for example), but possibly also as a result of a range of indirect effects (for instance the improved health of the cows, reduced costs for animal replacement, etc). Generally, the process of re-balancing is slow, incremental and often barely perceptible, although careful empirical analysis can highlight its presence and potential (Swagemakers 2002). In periods of transition (such as the present time) re-balancing of farming systems as a whole comes to the fore. The reduction of nitrogen surpluses entails a reduction of external resources (mostly concentrates and fertiliser). This implies farmers becoming more dependent on their own specific resources (such as soil, roughage and manure) and needing to adapt their production system to their specific conditions. For instance, a reduction in the use of fertiliser will lead to a change in the quality of the pastures and the roughage produced. These changes in turn require an adaptation – or a re-balancing – of the type and amount of concentrates used, the optimal productivity and longevity of the cows, ideal breed of the cows, the type of grassland, and so on and so forth. Eventually, this downgrading will lead to an increase of heterogeneity amongst farms and farming practices.

This in turn implies that the need for farm and locally specific solutions will increase and that generic solutions will become less relevant.

Farmers' knowledge

A fourth important element of the nutrient management project was the direct contact between farmers and scientists and the use that was made of farmers' knowledge in the project. Farmers have years of experience and knowledge in organising and optimising their farms. This knowledge is not only based on scientific insights but farmer experimentation and experiences also play an important role (Stuiver *et al.* 2002). Often these two types of knowledge are expressed in different ways. To understand the underlying principles of improving nutrient efficiency, farmers and scientists had to explain their knowledge and experiences to each other. Farmers were encouraged to experiment with nutrient management on their farms and the results were discussed thoroughly with other farmers and scientists. These discussions were crucial: they contributed to the construction of shared hypotheses. Farmers and scientists enhanced their understanding about the data in the model and came to understand why nutrient flows varied between farms and how farmers influenced this by managing nutrient flows.

Besides increasing knowledge, these discussions generated enthusiasm amongst farmers and scientists and stimulated the farmers to actively implement new management strategies. The discussions also strengthened the confidence of the farmers in their own knowledge and decision making capabilities. Another consequence of the direct contact between farmers and scientists was to reduce the risk of misunderstanding between the two groups: differences in perceptions and language had to be overcome in direct discussion. During an evaluation of the project one of the farmers stressed the importance of these elements of the project:

> *'Social cohesion, curiosity, farmers teaching farmers, these all are very interesting elements of the project. There is a lot of knowledge at 'Wageningen'* [5]*, but the farmers do not know what to do with it. But through encouraging farmers to learn together, the results become more clear for the farmers.'*

This illustrates the importance of the direct interaction between the farmers and scientists involved in the project. The farmer describes the project as a joint learning process in which scientific and experiential knowledge were both crucial elements. In this respect the project can be seen as a field laboratory (Stuiver 2003). This farmer also stresses the practical benefits bought about by the increase of the availability and applicability of scientific knowledge created by the project.

6.4 The hypothesis of the VEL and VANLA project

Soil-plant-animal-manure

The farmers and scientists shared a common interest in finding out whether nitrogen surpluses could be reduced without causing a loss in production. Possibilities for increasing the nitrogen efficiency of mixed farming systems were already being investigated at the A.P. Minderhoudhoeve prototype experimental farm in Swifterbant (from now on called the APM) (Lantinga and van Laar 1997). To a certain extent this acted as an inspiration and starting point for the participants in the VEL and VANLA-project. This section discusses how the VEL and VANLA nutrient management project incorporated the different influences described in the previous section.

The analysis described in textbox 1 was presented to the farmers in the form of a 'soil-plant-animal-manure-picture' (see Figure 2). Later on, this uncomplicated and holistic picture became the 'trademark' of the project. Although it did not include all the available scientific knowledge about nitrogen flows at farm level, the picture summarised the nitrogen flows on a dairy farm in an accessible way and also introduced the notions of a system approach, the importance of efficiency and the interdependency of the different subsystems. Analysis of the successful strategies of local innovators was incorporated into this model in order to try to develop a novel strategy capable of further reducing nitrogen surpluses.

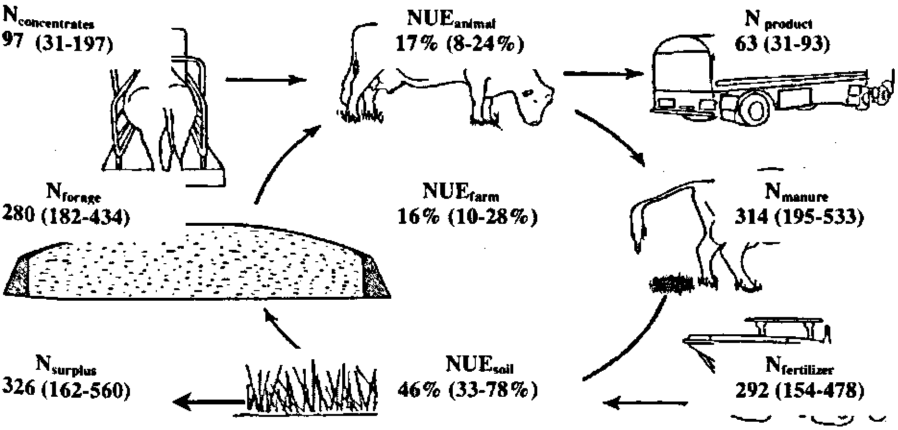


Figure 2 The characteristic soil-plant-animal-manure picture, showing average, minimum and maximum N flows (kg N ha^{-1} year $^{-1}$) and efficiencies (%) of 93 farms in the VEL and VANLA area in 1995/1996.

At around the same time, Lantinga and Groot (1996) concluded that under integrated grazing and cutting management N losses per unit product are minimised at a rate of 200 kg mineral N ha^{-1} yr^{-1}, leading to a reduction in production of only 10 per cent compared to grassland fertilised with 400 kg mineral N ha^{-1} yr^{-1}. Based on these and similar findings in Ireland and England, Lantinga stated in a popular magazine (Muller 1999) that the input of chemical fertiliser at farm level could be much lower than the current Dutch fertiliser recommendations without a significant loss in grassland production.

On this basis, a significant reduction in levels of fertiliser use was formulated as one of the main priorities in the project. It was concluded that the key to reducing nitrogen surpluses was to improve the N efficiency of the soil. A more efficient soil would need fewer inputs (manure and/or fertiliser) to produce the same output (roughage). To achieve this it would be necessary to improve the utilisation of nitrogen contained within the manure produced on the farms. This could then lead to a gradual decrease in the need for *external* fertiliser. As in other projects running at the same time (e.g. Aarts 2000), this became the main aim.

Cows have a low digestive efficiency for N (e.g. Castillo *et al.* 2000). Approximately 75-80 per cent of the nitrogen ingested by a dairy herd is secreted in faeces and urine. Most farms in the Netherlands do not separate faeces and urine, but produce slurry manure, which has a high inorganic nitrogen content, which is highly volatile and easily lost to the atmosphere. Reducing volatilisation increases the efficiency of use of the nitrogen contained in the slurry. There are different ways to approach this. One strategy involves employing technical solutions, such as low emission stables or soil injection of manure. Another involves preventing emission by decreasing the inorganic N content of the slurry. The VEL and VANLA project choose to explore the possibilities of this second strategy. They recognised such a strategy might reduce the need for expensive technical solutions such as roofing manure storage areas, installing low emission stables or injecting the slurry manure into the soil.

However, as we noted earlier, a change in one part of the farming system also requires a re-balancing of the whole. A reduction in the inorganic N content of slurry manure (combined with a lower fertiliser use) implies that plant growth will become more dependent on organic N. This however is not directly available to the plant but has to be converted by soil micro-organisms. This led the VEL and VANLA project to seek to change soil management so as to improve conditions for soil micro-organisms, though avoiding the use of heavy machinery and experimenting with microbial additives. They adopted the C:N (carbon : nitrogen) ratio of the slurry manure (widely used in organic farming) as an indicator of its quality. Increasing the C:N ratio of the slurry implied a change in the cows' diets, reducing the amount of protein and increasing the fibrous content. In addition, straw was added to the slurry and some farmers used additives that they expected to further improve the C:N ratio.

It was also anticipated that a gradual decrease in the amount of fertiliser used would lead to a decrease in the N content of the roughage produced on the farms. Cutting the grass later in the season would complement this and increase the fibrous material within the roughage. The roughage would therefore play a key role in the transition to high fibre/low protein diets. These diets would, in turn, increase the C:N ratio, and decrease the inorganic N content of the manure. Together these changes made a coherent and complete hypothesis. The challenge for the farmers was to apply these measures gradually, in such a way as to maintain their production levels. If they succeeded the N efficiency of their farms could gradually be increased and nitrogen flows through the system could be reduced.

Data collection in the project

The VEL and VANLA project started in 1997 and involved 60 farmers. In the first years the project team consisted of only a few members. The most important job for the project team was to stimulate the farmers and guide them by a rapid exchange of results and insights (see Stuiver and Wiskerke in this volume). The main aim was not to collect data for scientific research but to improve results at the farm level. Therefore, it was not possible for the team to collect detailed and accurate data for every farm. Choices had to be made in data collection. The results of this monitoring/data collection and the conclusions that can be drawn from them are discussed later, in Section 6.6.

Despite this, continuous monitoring of data and knowledge exchange were important pillars of the project. The farmers were continually adjusting the component parts of their farms: their fields, their manure, their management, their feeding etc. in order to find a new ecological and economical optimum, one characterised by an undiminished level of production, considerably reduced nitrogen surpluses and, in the end, a higher income. The farmers worked together with the scientists and explored the possibilities for their specific situation, using the whole toolbox of available measures. This diversity of experience makes the project rich and complex but, from a conventional scientific (and reductionist) perspective, also controversial, as it is difficult to separate or quantify the effects of individual measures separately from the others.

6.5 A typical feeding strategy in the nutrient management project

Feeding strategies

One key element of the VEL and VANLA project was to develop a new feeding strategy. This section outlines some of the technical and theoretical issues involved in this.

Different objectives can be used to guide the formulation of diets for cows. For example, one can aim to maximise milk production (quantity and/or composition), the health of the cows, or to reduce the amount (and cost) of purchased feed. Bearing these objectives in mind, farmers search for an optimal equilibrium that takes account of the specific conditions on their farms and their preferred farming style (van der Ploeg 2003).

Several researchers have discussed the importance of feeding strategy in the context of reducing nitrogen surpluses (Tamminga 1996; Castillo *et al.* 2000; Børsting *et al.* 2001). If a reduction of nitrogen surpluses is a priority, then diet formulation becomes more dependent on the resources within the farming system. This will have the combined effect of reducing the amount of nitrogen imported in purchased feed and improving nitrogen efficiency at animal level. Diets with protein values that just meet requirements can still maintain high production levels, while reducing levels of nitrogen intake. Under these conditions the nitrogen use efficiency of individual animals can be increased from around 20 per cent to around 35-40 per cent (Tamminga 1996). Theoretically, the N loss of a 600 kg cow, producing 25 kg milk d^{-1} (5.2 g N kg^{-1}) and fed on a well-balanced (in terms of energy and protein) diet could be as little as 170 g N d^{-1}. In this ideal situation the efficiency of use of dietary N is almost 45 per cent (van Vuuren and Meijs 1987). A very small proportion of N is lost to the skin and hair. The remainder is endogenous urinary N and metabolic faecal N excess related to maintenance and milk production processes (about 70 and 100 g N d^{-1}, respectively). Assuming a daily dry matter (DM) intake of about 20 kg cow^{-1} d^{-1}, the N content of the diet can be calculated to be about 15 g kg^{-1} DM. This is equivalent to a crude protein (CP) content of 95g kg^{-1} DM. However, in practice this ideal situation can never be reached because in such a protein-poor diet the protein-nutritional value (DVE)[6] content will be insufficient to produce enough milk protein. Feeding experiments at APM have revealed that, in practice, the efficiency of utilisation of dietary N can reach about 35 per cent at most with cows producing 8500 kg milk yr^{-1} (5.4 g N kg^{-1}). In this situation, the optimal N content of the diet was about 20g kg^{-1} DM or 125 g CP kg^{-1} DM.

The strategy developed at APM and promoted in the VEL and VANLA project sought to go beyond merely reducing protein content (see Figure 3). Reduction of the surpluses at farm level is not only a matter of efficient use of nitrogen at animal level. As noted in previous sections, animal efficiency is not the most important step in the reduction of surpluses at farm level. Improving N efficiency at farm level involves increasing the use of internal farm resources, specifically the contained N in manure. The production of high quality manure should be no less important than the production of high quality milk. In terms of the system approach: the optimisation of the animal subsystem should be subordinate to the optimisation of the whole system. The main difference between 'regular' low protein diets and the diets fed at APM and promoted at the VEL and

VANLA farms was that the latter also aimed to increase the diets' fibre content. The underlying idea was to increase the organic matter content of the manure (and thereby increase its C:N ratio) by increasing the amount of indigestible matter in the diet (Tamminga *et al.* 1999).

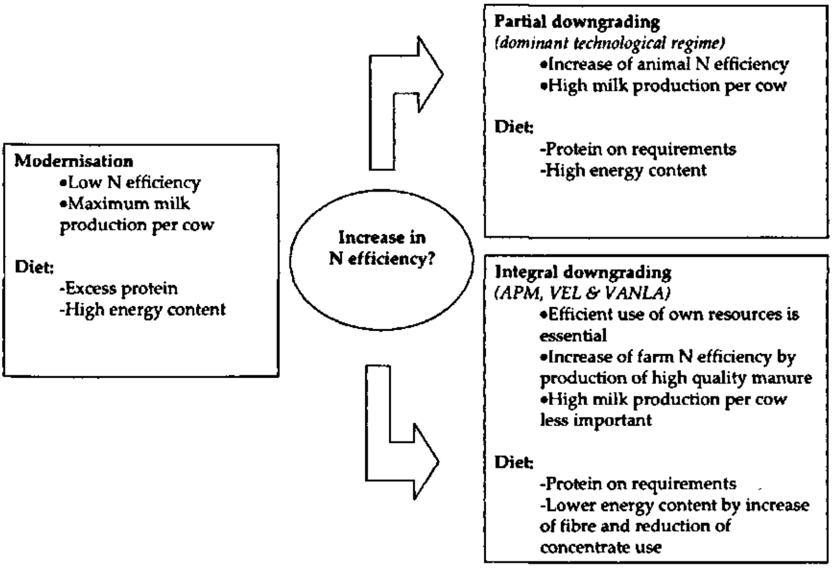


Figure 3 Schematic overview of the effects on diet type from two pathways of downgrading external N in dairy farming systems.

Effects of high fibre/low protein diets

High fibre diets can be expected to yield several positive effects. First of all, an increased amount of indigestible matter in the rumen decreases the risk of rumen acidosis by increasing the size of the fibre pool in the rumen and mechanical stimulation of the rumen wall (van Soest 1994). In the second place, sufficient indigestible matter stimulates rumination, which encourages more efficient use of nitrogen in the rumen due to the reflux of nitrogen via saliva and the rumen wall (van Soest 1994). Furthermore, the passage of more undigested organic material through the gut changes the fermentation pattern in the large intestine and leads to an increase of endogenous nitrogen. This nitrogen can be used for the production of microbial biomass in the large intestine (van Soest 1994; Tamminga *et al.* 1999) and leads to a shift in nitrogen excretion from urine to faeces.

Of course negative aspects of the high fibre/low protein diets can also be expected. First of all, less readily digestible diets do not provide the same amount of nutrients per kg dry matter as diets with high digestibility (Tamminga 1995). Thus the same amount of feed intake contains fewer available nutrients, which has possible implications for milk production levels. Van Bruchem *et al.* (2000) compared two imaginary extreme diets and demonstrated that, in order to reach the same production level, the dry matter intake of a low energy/low protein diet would have to be 135 per cent of the intake of the high energy/high protein diet. Furthermore, one of the main limiting factors of feed intake, is the cell wall content of the feed, which is intrinsically high in high fibre diets. This implies that a high feed intake will be more difficult to achieve with these low energy/low protein diets. Therefore, to provide enough nutrients for a high milk production level, the intake capacity of low energy/low protein diets is of crucial importance. Tamminga and van Vuuren (1996) proposed the following formula for predicting feed intake:

$$DMI\ (g\ d^{-1}) = 6382 + 33.4\ FPCM + 11.3\ LW + 5.06\ CONC - 6.24\ NDFR$$

DMI = Dry Matter Intake

FPCM = Fat and Protein Corrected Milk (g kg$^{-0.75}$)

LW = Live weight of the cow (kg)

CONC = Proportion of concentrate dry matter (g kg^{-1})

NDFR = Neutral Detergent Fibre content of the roughage (g kg^{-1} DM)

This model has quite reliably predicted DMI for diets over a wide range of circumstances. However, experiments with total mixed rations conducted at the APM, which compared feed intake predictions based on this formula with the measured results, showed that this formula significantly underestimated the intake capacity of these diets. While the model predicted a DMI of 17.5 and 21.4 kg DM day^{-1} for the late and early lactation stages respectively the real DMI was far higher, at 20.2 and 24.8 kg DM day^{-1} respectively with milk productions of 24.2 and 36.3 kg day^{-1} FPCM. This suggests that the production possibilities based on low energy/low protein diets may be higher than expected, due to an unexpectedly higher feed intake capacity. Therefore, stimulation of the DMI became another important issue within the VEL and VANLA project. Most important in this respect is improving the appeal of grass silages.

Whilst important, the volume of available nutrients is not the only limiting factor for milk production. The type of available nutrients also plays an important role. For milk production, nutrients can be subdivided into precursors for three groups of components; lactose (glucogenic nutrients), protein (aminogenic nutrients) and fat (ketogenic nutrients). Model-based predictions (Dijkstra *et al.* 1992) show that glucogenic nutrients are main limiting for milk production in the Netherlands. In relatively high protein diets the shortage of glucogenic nutrients can be replenished by glucogenic amino acids, while de-amination increases urinary urea excretion. With low protein diets, fewer amino acids are available for glucogenic purposes and a shortfall of glucogenic nutrients could lead to a drop in milk production or milk protein content. Furthermore, high fibre diets stimulate the production of ketogenic nutrients (fat-precursors) leading to an increase of the fat content of the milk. Given the higher prices paid for protein (in comparison with fat) a high fat to protein ratio is not very attractive to Dutch dairy farmers. It is therefore extremely important to assemble a well-balanced diet that can provide enough (non-aminogenic) glucogenic precursors. Important factors in this respect are 1) sufficient rumen available energy to provide optimal microbial protein production and 2) sufficient availability of non-degradable starch as direct glucogenic precursors. In the longer term, breeding strategies based on the criterion of high milk protein content could also be developed.

Table 1 Development of average farm characteristics during the nutrient management project.

	1997/98	*1998/99*	*1999/00*	*2000/01*	*2001/02*	*2002/03*
Number of farms	50	50	50	50	49	48
Area grass (ha)	42.7	43.9	45.1	46.1	46.6	49.5
Area silage maize (ha)	2.2	2.5	2.4	2.3	2.7	2.6
Total milk production (kg year^{-1})	522,910	534,169	559,772	573,238	592,628	599,825
Number of milking cows	67.7	69.4	70.5	73.3	77.3	78.7
Rate of young stock (10 milking cows^{-1})	8.2	8.2	7.7	7.6	7.2	7.4
Stocking Density (GVE^{A}. ha^{-1})	2.0	1.9	1.9	1.9	2.0	1.8
Production intensity (kg milk ha^{-1})	116,62	11,534	115,33	11,651	11,844	11,449
Milk production (kg cow^{-1})	7,651	7,597	7,833	7,754	7,609	7,685
Fat content milk (%)	4.41	4.38	4.34	4.39	4.42	4.42
Protein content milk (%)	3.44	3.45	3.45	3.43	3.45	3.46

A GVE = Groot Vee Eenheid, stands for the total number of cattle converted to adult cattle units.

6.6 Technical results of the nutrient management project

Farm performance

Table 1 provides details of a number of key characteristics of the farms participating in the project[7]. The table shows that, in general the farms increased their total size during the project. This increase mostly involved increasing the available grassland area, while the percentage of the area used for silage maize remained stable. There was also an increase in total milk production from 523 tonnes milk year^{-1} in 1997/98 to 600 tonnes milk year^{-1} in 2002/03. Production intensity and milk production per cow both remained relatively stable throughout the project. There was a slight decrease in stocking density, mainly due to a reduction of the number of young stock maintained on the farms. The fat and protein content of the milk produced remained stable.

Reduction of N surpluses

The main goal of the project was the reduction of N surpluses. Table 2 shows the changes in N balances of the participating farms. The average N surplus decreased from 299 kg ha^{-1} in 1997/1998 to 156 kg ha^{-1} in 2002/2003. By 2002/2003, 77 per cent of the VEL and VANLA farms met the thresholds set by legislation for 2003 (the following growing season). The efficiency of N use at the farm level has increased from an average 19 per cent in 1997/1998 to 31 per cent in 2002/2003. The decrease of the N surplus was mainly achieved through a reduction of fertiliser inputs, which fell from 270 kg N per ha in 1997/1998 to 126 kg N per ha in 2002/2003.

Table 2 Progress (mean ± standard deviation) of the VEL and VANLA farms over the period 1997/98-2002/03 (n=50)

	1997/98	*1998/99*	*1999/00*	*2000/01*	*2001/02*	*2002/03*
N input (kg N ha^{-1})	369 ± 77	336 ± 84	284 ± 76	244 ± 72	240 ± 70	227 ± 57
Feed	97± 30	101 ± 30	93 ± 28	89 ± 25	102 ± 31	99 ± 31
Inorganic fertilizer	270 ± 69	233 ± 73	181 ± 72	149 ± 63	134 ± 58	126 ± 39
Organic manure	2 ± 9	2 ± 8	10 ± 21	6 ± 13	4 ± 10	2 ± 10
N output (kg N ha^{-1})	70 ± 19	72 ± 14	70 ± 16	69 ± 13	71 ± 12	71 ± 14
Milk	57 ± 12	59 ± 10	59 ± 11	59 ± 10	60 ± 12	59 ± 11
Meat	10 ± 4	11 ± 4	10 ± 3	10 ± 4	11 ± 4	12 ± 6
Roughage	1 ± 6	1 ± 3	0 ± 5	0 ± 0	0 ± 1	0 ± 2
Organic manure	2 ± 8	1 ± 8	1 ± 5	0 ± 1	0 ± 1	0 ± 1
Surplus (kg N ha^{-1})	299 ± 82	264 ± 84	214 ± 69	175 ± 65	169 ± 62	156 ± 48
N efficiency at farm level (%)	19 ± 5%	21 ± 6%	25 ± 6%	28 ± 6%	30 ± 6%	31 ± 6%
Farms that meet legislation 2003 (%)	8%	14%	31%	44%	63%	77%

However, the average N output (in milk and meat) did not change over this period, indicating that the farms were able to maintain their productivity. Over this six year period there was no increase in the input of feed-based N onto the farms, indicating that it was not necessary to compensate for the reduction of fertiliser N through extra feed N inputs.

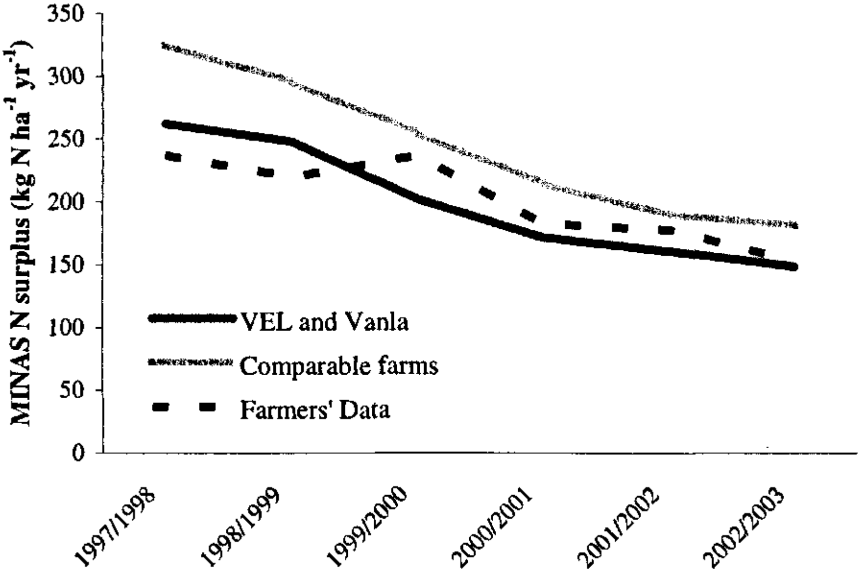


Figure 4 Progress of MINAS N surplus of the VEL and VANLA farms in comparison with the Farmers' Data project (Doornewaard 2002) and a reference group of local farms (Anon. 2003).

In Figure 4 the N surplus of the VEL and VANLA farms is compared with the results of the Farmers' Data project (Doornewaard 2002) and a reference group of dairy farms in Friesland (Anon. 2003). This graph shows that all three groups had considerable success in reduction of N surpluses although the surpluses remain higher on the farms of the reference group. It is worth noting that considerably more farmers from the VEL and VANLA project meet the 2003 target thresholds farms, compared to those from the Farmers' Data project (77 per cent and 56 per cent respectively). Moreover many farms in the VEL and VANLA project are going further and reducing their surplus below the legal thresholds. The reduction of N surplus in the VEL and VANLA project was also accompanied by a re-moulding of resources and the re-balancing of the soil-plant-animal-manure system. The main features of these changes are summarised below.

Changing grass silage as a part of the re-balancing strategy

Grass silage plays an important role in the soil-plant-animal-manure-system. On most dairy farms, grass or grass silage forms the major part of the cows' diet. In terms of system theory it constitutes the most important link between the soil and animal subsystems. One of the main aims of the project was to produce silage with a lower CP (crude protein) content (mainly as a result of the reduction of fertiliser use) and a higher CF (crude fibre) content (by cutting the grass at a more mature stage). In this way the silage would provide diets that were higher in fibre and lower in protein.

The chemical composition of grass silage depends on several other factors than the fertilisation level and maturity of the grass at cutting. Weather conditions play a particularly important role in determining these. To obtain an idea about their influence, the composition of silage produced on the VEL and VANLA farms between 1997 and 2001 was compared with the national average (Anon. 2002). The results (Table 3) show considerable annual fluctuations for both groups of farms and we assume that a large part of this variation is due to differences in weather conditions that applied equally to both groups.

Table 3 Grass silage characteristics (mean ± standard deviation) of the VEL and VANLA (V&V) farms, in the 1997-2001 period, compared with national (BLGG) characteristics (Anon 2002)

Year	Source	n	DM (g kg^{-1})	CP (g kg dm^{-1})	CF (g kg dm^{-1})	Sugar (g kg dm^{-1})	DVE (g kgdm^{-1})	OEB (g kgdm^{-1})
1997	V&V	111	453 ± 84	179 ± 21	248 ± 13	64 ± 34	65 ± 8	66 ± 27
	BLGG		436	182	253	64	66	68
1998	V&V	146	432 ± 95	166 ± 22	250 ± 21	72 ± 35	68 ± 12	48 ± 22
	BLGG		415	174	252	60	70	58
1999	V&V	144	503 ± 76	158 ± 19	243 ± 15	123 ± 38	74 ± 7	28 ± 19
	BLGG		494	180	242	102	78	50
2000	V&V	112	460 ± 82	167 ± 19	258 ± 15	75 ± 39	72 ± 7	44 ± 24
	BLGG		480	176	256	74	76	51
2001	V&V	97	489 ± 63	155 ± 16	248 ± 30	106 ± 34	74 ± 6	24 ± 16
	BLGG		516	173	251	113	81	37

Over the longer term noticeable differences emerge between the two groups. In 1997 (the year before the project started) there was little difference in the CP and CF content of silage produced on farms participating in the project and the national average. During the course of the project, the VEL and VANLA farmers reduced the CP content of their silage. An important consequence of this reduction was the reduction of

OEB[8], an indicator of possible surplus rumen N caused by feed stuffs. The reduction of CP content did not lead to a loss of the protein-nutritional value of the silages. The average DVE-content of the silages in the project even showed a slight increase, though this increase was smaller than at national level.

Regular contact with the farmers showed that, in general, they postponed cutting their grass. However, this did not, as anticipated, lead to an increase in the average CF content of silage produced by the VEL and VANLA farmers (at least in comparison with the national average). The figures do however, reveal a growth in the standard deviation of the CF content for VEL and VANLA farms in 2001, indicating that variation in the CF content is increasing. This suggests that, after four years of the project, a turning point has been reached in silage making, with different farmers adopting different strategies and achieving different results. In turn, this illustrates a growth in the heterogeneity of farms and their strategies.

Changes in diet composition in the project

From the second year of the project onwards (autumn 1999) the project also focused on changes in diet composition. From the first findings at the APM experimental farm, guidelines were formulated for diet composition on the VEL and VANLA farms. These guidelines can be summarised as follows:

- Limit CP (Crude Protein) to • 150 g.kg^{-1} dm
- Limit OEB (degraded protein balance) to 0 g^{-1} d
- DVE-values (true protein digested in the small intestine) must fulfil requirements for maintenance and milk production
- Limit VEM[9] (net energy content) to $\leq$ 900 kg^{-1} dm
- Limit the use of concentrates to $\leq$ 25 kg 100 kg^{-1} FPCM.

Farmers were encouraged to work towards these guidelines. Diet composition and intake were recorded three times during the winter months (although no data were recorded in 2000/2001). Table 4 shows the changes in diet composition over the first years of the project. The guidelines and the first results were thoroughly discussed by small groups of farmers. In 1999/2000 a significant reduction of the average protein content (CP) was achieved and this was stabilised after two years. This reduction of the CP was mainly attributable to a reduction of OEB in the diet from 589 g day^{-1} in 1998/99 to 277 g day^{-1} in 2001/02 (Table 4). The farmers also succeeded in decreasing the use of concentrates from 30.6 kg (100 kg)$^{-1}$ FPCM in 1998/99 to 24.8 kg (100 kg)$^{-1}$ FPCM in 2001/02. Under these conditions milk production per cow in winter period increased, as did the fat and protein content of the milk. There was no reduction of the average net energy content (VEM) of the diets in winter and the CF content remained unchanged. Overall these results suggest that the effects of the typical aspect of feeding strategy, i.e. the increase of the amount of indigestible matter in the diet have not (yet) been very pronounced. However, the increase in the fibre in diets has led to other subtle changes whose impact lies outside these dietary characteristics. Apart from changes in silage quality (discussed previously), there has been an increase in the use of small amounts of fibrous products such as nature conservation grade hay and straw which are used to complement diets that have a shortage on fibre.

Table 4 Winter diet and production characteristics (mean ± standard deviation) of the VEL and VANLA farms: 1998/99-2001/02

Year	*1998/1999*	*1999/2000*	*2001/2002*
Number of farms (n)	46	46	46
Average diet composition			
VEM (kg^{-1} dm)	939 ± 32	936 ± 33	940 ± 27
CP (g kg^{-1} dm)	167 ± 15	157 ± 13	157 ± 12
OEB (g cow^{-1} day^{-1})	589 ± 218	312 ± 222	277 ± 188
CF (g kg^{-1} dm)	198 ± 17	201 ± 13	203 ± 18
Concentrates use			
(kg cow^{-1} day^{-1})	7.1 ± 1.7	6.4 ± 1.6	6.4 ± 1.6
(kg 100 kg^{-1} FPCM)	30.6 ± 6.7	27.4 ± 5.6	24.8 ± 5.1
Roughage			
VEM from own farm (%)	60.1 ± 8.1	63.4 ± 6.7	62.2 ± 7.0
OEB (g kg^{-1} dm)	38 ± 19	18 ± 17	12 ± 14
CP (g kg^{-1} dm)	157 ± 21	144 ± 18	140 ± 16
CF (g kg^{-1} dm)	235 ± 16	236 ± 15	241 ± 20
Production			
Milk (kg cow^{-1} day^{-1})	23.9 ± 3.1	23.8 ± 3.2	25.6 ± 3.2
Fat content (%)	4.50 ± 0.21	4.55 ± 0.18	4.60 ± 0.21
Protein content (%)	3.46 ± 0.12	3.49 ± 0.10	3.51 ± 0.13
N-efficiency (%)	24.9 ± 2.5	26.7 ± 2.4	26.6 ± 2.4

During the project farmers increased their knowledge about the relationship between the composition of diet and manure, milk production and the health of the cows. As a result they have become more confident in decision-making and less dependent on advice from feed suppliers. Furthermore there has been a tremendous change in perception of the way diets should be composed. Objectives have shifted from high production levels towards manure quality, cow health and economic performance. This is illustrated by the following quotes from farmers in the project:

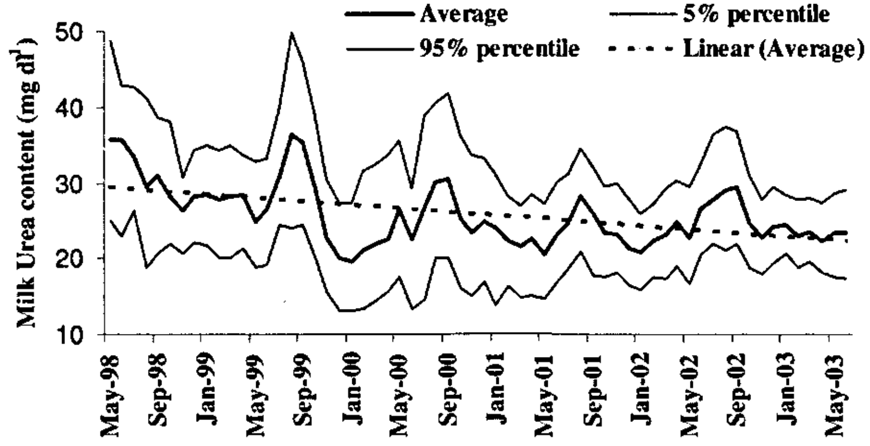
> *'In the past we wanted the manure of the cows to be as thin as possible. Then you had the maximum milk production. That is how we did it for years. But the quality of the manure those days was bad. It was an inevitable waste product. Now we try to combine optimal milk production with optimal manure quality. That is quite a different attitude...'*
>
> *'....Now it is different, we have less sick cows. We feed more fibre, the rumen of the cow has to function properly. We don't ask for that maximum production anymore.... That is our choice.'*
>
> *'I am not looking for that high production anymore. That is not what it is about. With the reduction of feed costs, we are increasing the economic performance'*

Milk Urea Nitrogen as a tool

Measurements of Milk Urea Nitrogen (MUN)[10] provide a simple indicator that can be used to monitor N excretion from lactating dairy cows. It is used as a management tool to improve dairy herd nutrition (Jonker *et al.* 1998) and can help reduce excessive flows of nitrogen within the animal sub-system. Research carried out at the University of Pennsylvania has revealed that average MUN values for cows fed a well-balanced diet typically fall in the range of between 10-14 mg dl^{-1} (Ferguson 2001). According to the Dutch Research Centre for Cattle Husbandry, optimum MUN for the total herd should be slightly higher, in the range of 11.5-14 mg dl^{-1} (Anon. 1997)[11]. These figures provide a safety margin to ensure that individual cows are not subject to a negative OEB. However, theoretically, OEB values might be zero if the DVE value of the diet is sufficient to meet the cow's dietary requirements. In fact, to ensure recycling of N in the rumen, OEB has to be negative. As MUN has been shown to have a positive relation with urinary N excretion (Jonker *et al.* 1998; Kauffman and St. Pierre 2001) many farmers in the nutrient management project adopted a target of low MUN values of between 9-10 mg dl^{-1}.

Since 1998 milk urea levels have been monitored in the Netherlands. Figure 5 shows the results of milk urea content of the farms participating in the project. The figure shows that milk urea content displays strong seasonal fluctuations, with high peaks during the grazing seasons. Over the course of the project this fluctuation decreased, indicating that the farmers improved their control over the milk urea content. This may be due to either better management or lower N-contents of the grass and grass silages. The linear regression line in Figure 5 indicates an average reduction of milk urea content from 30 mg dl^{-1} at the beginning of the project to 23 mg dl^{-1} at the end (a reduction in terms of MUN from 14 to 11 mg dl^{-1}). According to a formula developed by Kauffman and St. Pierre (2001) this reduction in MUN would imply a reduction of urinary N excretion of 52 g cow^{-1} day^{-1}. Given that 42 farms participated in this experiment, and, assuming an average herd size of 60 milking cows, this implies an annual overall reduction of almost 50 tonnes of urinary N excretion. While this is already a significant reduction, regular contacts with commercial farmers throughout the country and (unpublished) results of APM show that it is possible to achieve MU levels as low as 5 mg dl^{-1} without affecting milk production level or animal health. This shows that there remains a large potential for further increasing nitrogen efficiency at animal level.

Figure 5 Changes in Milk Urea content (mg dl^{-1}) on VEL and VANLA farms (N=42) during the nutrient management project.



Changes in manure quality?

Several studies have shown that nutrition management can substantially contribute to a reduction in ammonia emissions (Smits *et al.* 1995; Külling *et al.* 2001). Phillips *et al.* (1999) reviewed different approaches for reducing ammonia emissions from livestock buildings and identified the best options as 1) dietary manipulation and 2) increasing the C:N ratio by generous use of bedding. These were the two main strategies adopted in the VEL and VANLA project, through which the farmers aimed simultaneously to increase the C:N ratio and to reduce the inorganic N content of their slurry manure. Both strategies aimed to reduce gaseous emissions. Table 5 shows the extent to which the farmers succeeded in these aims. The winter of 1999/2000 was the first period that the project focused on feeding high fibre/low-protein diets. The average inorganic N content of the slurry decreased, while the percentage of organic N and the C:N ratio increased. Most striking is the change in inorganic N, which decreased by 28.6 per cent. These findings are in line with the decreased urinary N excretion suggested in the previous section. According to Erisman (2000) this reduction in inorganic N would imply a considerable reduction of ammonia volatilisation. A good impression of the underlying changes can be obtained from the percentage of farms that produce slurry manure containing less than 50 per cent inorganic N (Table 5, last column). In 1996, an average 54 per cent of N in Dutch slurry manure was in inorganic form (Mooij 1996). In 2002, 93 per cent of the VEL and VANLA farmers had levels below 50 per cent.

Table 5 Slurry manure characteristics (mean ± standard deviation) of the VEL and VANLA-farms in the period 1998-2002 (one sample per farm per winter), in comparison with standard values (Mooij 1996).

	n	*DM* *(g.kg^{-1})*	*OM*[A] *(g.kg^{-1}dm)*	*Total N* *(g.kg^{-1}dm)*	*Inorganic N* *(g.kg^{-1}dm)*	*%* *Inorg. N*	*C:N*[B]	*# Farms* *< 50% Inorg. N*
1998	54	90 ± 19	718 ± 40	52 ± 7	28 ± 8	53 ± 10	7.0 ± 1.0	29%
1999	54	93 ± 24	705 ± 52	54 ± 11	30 ± 10	56 ± 10	6.8 ± 1.4	18%
2000	54	96 ± 14	737 ± 35	51 ± 7	24 ± 7	46 ± 8	7.3 ± 1.1	69%
2001	47	99 ± 20	718 ± 62	50 ± 7	20 ± 6	40 ± 11	7.3 ± 1.1	86%
2002	45	92 ± 15	752 ± 32	47 ± 6	20 ± 5	42 ± 8	8.1 ± 1.2	93%
Mooij (1996)		90	733	54	29	54	6.8	-

[A] Organic Matter

[B] The C:N-ratio is calculated as (0.5*OM)/2. The assumption is made that 50 per cent of the organic matter is C.

Besides reducing gaseous N emissions, changes in manure composition can be expected to induce other effects. When animal manure is used as a fertiliser it has two effects: 1) the short-term release of nutrients and 2) an increase in soil fertility status. These effects are, in turn, a function of the stability of the organic compounds in the manure, which can vary significantly between different manure types. Factors, which influence this include, the type of animal, the way the manure is stored and the composition of the diet. In general, the soluble inorganic fraction in urine is available almost immediately, the gastro-intestinal (endogenous) secretions and microbial matter excreted in the faeces are rapidly degradable and the undigested feed fraction is usually slowly degradable in soil (Velthof *et al.* 2000). Slurry produced under the feeding strategy adopted by the VEL and VANLA project is likely to contain less soluble inorganic (urinary) N and a more microbial matter, endogenous material and undigested feed. It is anticipated that this will reduce the short-term release of N (Reijs *et al.* 2003) and should make a positive contribution to soil fertility in the longer term.

At the APM, the amount of total nitrogen in the top soil layer (0-30 cm) has increased by about 90 kg per ha per year between spring 1996, when the alternative feeding strategy and use of straw as a bedding material was adopted, and spring 2002 (unpublished results). This increase in total soil nitrogen should gradually lead to an increase in the soil nitrogen supply for plant uptake (Langmeier *et al.* 2002; Silgram and Chambers 2002). Furthermore the changed feeding strategy should also reduce the rate of herbage rejection by grazing cattle following slurry manure application and decrease the phytotoxicity of dairy farm slurries (Reijs *et al.* 2003).

6.6 Concluding remarks

The project started with a group of farmers and scientists who were convinced that nitrogen losses could be reduced without reductions in production levels or incomes. As described in the first three sections, this hypothesis was inspired by existing heterogeneity in practice, which was assumed to have the common characteristics of achieving a 'certain balance' on the farms. By combining local farming practices and specific scientific insights, a toolbox of measures was developed to reduce nitrogen losses by improving the balance between different farm subsystems. The proposed feeding strategy was relatively new to most of the farmers and some farmers were initially hesitant about this approach, which appeared to contradict their generally accepted frames of reference. However, during the project quite a few farmers became enthusiastic about this approach and started to experiment with 'the toolbox' on their farms.

In general, the main goals of the project have been achieved. In 2002/2003, 77 per cent of the farmers had achieved the target set by the government for the next growing season. Production levels per hectare were maintained and production per cow increased slightly. A first analysis of economic data from the farms in the project reveals that involvement in the projects substantially contributed to the profitability of the farms (van der Ploeg *et al.* 2003). Most of the farmers are convinced that the nutrient management project has had a positive effect on their income. This is illustrated by a quote from one of the VEL and VANLA farmers.

> *'Now we are in control of the nutrient cycle, we know that we have spoiled a lot of things for a long time, not only with respect to the nutrients but also financially'.*

As expected, the reduction of external inputs and the adoption of the toolbox of measures caused a chain of reactions on the farms. A reduction in fertiliser use was followed by a reduction in the protein content of the silage, changes in the diet composition, milk urea content, manure composition and so forth. In an interview one of the farmers phrased it like this:

> *'Less fertiliser use implies other feeding. A few years ago my silage and grass were dark. Now it has become lighter. This has got to do with the nitrogen utilisation, which was far too low, both in the animals and in the soil.'*

After 4-5 years of experimenting, reducing inputs, and searching for the right solutions for their specific situation, several farms seem to have reached a new equilibrium. Others are still searching. This new equilibrium can vary quite a lot between farms. In general, farmers are becoming more dependent on their own specific resources and their own management strategies. This implies that the management and skills of the farmer and their knowledge about specific, locally available resources are becoming more important. Increasingly these farmers have to adapt generic solutions relevant to their own specific situation and resources. The VEL and VANLA farmers have followed a variety of strategies that achieved the challenge facing the Dutch dairy sector: that of reducing their nitrogen surpluses very rapidly.

In this respect, the VEL and VANLA project can be seen as an example of the potential and importance of the skills and resourcefulness of farmers in harnessing farm specific resources to meet the more stringent new thresholds for nitrogen surpluses. The specificity of circumstances such as, soil types, position and size of fields, intensity, farm-size, and the quality of roughage and manure, all demand the development of specific knowledge and solutions. Any increase in the heterogeneity of resource use will have implications on the way in which research for, and advice to, farmers is organised. This new situation requires a greater contextualisation of research and advice services.

The nutrient management project has been successful through 1) combining local and scientific insights into promising practices, 2) implementing these practices at farm level, 3) testing and adapting these practices at farm level and 4) propagating the successful practices. The project has had a large impact on the national, as well as the regional, level. Various forms of knowledge dissemination, including magazines, newsletters, a website, excursions, lectures, courses, conferences and debates in different public media, have spread awareness of the project throughout the country. The characteristic soil-plant-animal-manure-picture has been displayed at local and national meetings about the improvement of nutrient efficiency. Through such activities, the project has been one of the triggers of a growing discussion among scientists, experts and farmers on scientific research methods (Stuiver *et al.* 2003).

The project has always considered the balance of the production system to be crucial. This balance needs to be created by farmers, moulding their own resources so as to create a coherent whole. The use of multivariate analysis might help to understand some of the complex interactions within these newly emerging patterns (Verhoeven *et al.* 2003). However, the re-balanced practices that have emerged from these changing production systems, also raises new research questions that require 'mono-causal' technical research. For instance: to what extent can feeding strategy influence manure quality? What is the effect of the changed diets on different aspects of animal health? What is the effect of different manure quality, or composition, on grass yields? How to improve soil functioning? What is the effect of different manure types on soil functioning? What is the effect of the use of additives or straw in manure? The VEL and VANLA project cannot provide solid answers to all these questions. Further experiments, under more controlled circumstances, are needed to elucidate the changing mechanisms in this new, re-balanced, soil-plant-animal-manure-system that is running on far lower levels of external inputs than before.

However, answering these questions will not necessarily lead to the development of a sustainable and nutrient efficient dairy-farming sector. System innovation and transition in agriculture has to be based on the innovative work of farmers (Roep *et al.* 2003a). There are many farmers, throughout the Netherlands, making innovative experiments designed to improve nutrient efficiency (Roep *et al.* 2003b). These farmers have developed interesting novelties and often show surprisingly positive results. We argue that the contextualised knowledge that is already available and that has been produced on these farms is essential for any effective transition towards a really sustainable dairy farming. Therefore it is highly important that 1) scientific community comes into (or stays in) contact with these farmers to find solid answers to the complex questions of sustainability and 2) governmental organisations create sufficient 'room for manoeuvre' (Roep *et al.* 2003a) for innovative farmers to continue further development of their promising novelties.

References

Aarts, H.F.M. (2000), Resource management in a 'De Marke' dairy farming system. Wageningen University, Wageningen, 222 pp.

Anon. (1994), It Lânjuwiel: voorbeeldplan van de vereniging Eastermar's Lânsdouwe. Vereniging Eastermar's Lânsdouwe, Eastermar, 41 pp. (In Dutch)

Anon. (1997), Handboek Melkveehouderij. Research Station for Cattle, Sheep and Horse Husbandry (PR), Lelystad, 519 pp. (In Dutch)

Anon. (1999), Groepsgemiddelden, Rapport AlfaBeag. AlfaBeag, Leeuwarden. 10 pp.

Anon. (2002), 13/6/2002, Dutch average of silages between 2002–1997, http//www.blgg.nl, 15/1/2003. (In Dutch).

Anon. (2003), AlfaBeag Groepsgemiddelden, Rapport AlfaBeag. AlfaBeag, Leeuwarden. 10 pp.

Børsting, C.F., T. Kristensen, L. Misciatelli, T. Hvelplund and M.R. Weisbjerg (2003), Reducing nitrogen surplus from dairy farms: Effect of feeding and management. *Livestock Production Science* 83-2/3: 165-178.

Bouma, J. (1997), Soil environmental quality, a European perspective. *Journal of Environmental Quality* 26: 26-31.

Brandt, H.M.P. van den, and H.P. Smit (1998), Mineral accounting: the way to combat eutrophication and achieve the drinking water objective. *Environmental Pollution* 102: 705-709.

Bruchem, J. van and S. Tamminga (1997), Sustainability and the future of animal production: options for environmental tuning of the systems in the Netherlands for Nitrogen, Phosphorus and Potassium. In: Proceedings of the 47th Annual Meeting of the Canadian Society of Animal Sciences, Montreal, Quebec, July 24-26 (1997. McGill University, Montreal. pp. 48-67.

Bruchem, J. van, J.B. Schiere and H. van Keulen (1999), Dairy farming in the Netherlands in transition towards more efficient nutrient use. *Livestock Production Science* 61: 145–153.

Bruchem, J. van, M.W.A. Verstegen and S. Tamminga (2000), From nutrient fluxes in animals to nutrient dynamics and health in animal production systems. In: D. Gagneaux, R Daccord, A. Gibon, J.R. Poffet and A.R. Sibbald (Eds), Proceedings of the Fifth International Symposium on Livestock Farming Systems. Posieux (Fribourg), Switzerland 19-20 August 1999, Wageningen Pers, Wageningen. pp. 28-48.

Castillo, A.R., E. Kebreab, D.E. Beever and J. France (2000), A review of efficiency of nitrogen utilisation in lactating dairy cows and its relationship with environmental pollution. *Journal of Animal and Feed Sciences* 9 (1): 1-32.

Dijkstra, J., H.D.St.C. Neal, D.E. Beever and J. France (1992), Simulation of nutrient digestion, absorption and outflow in the rumen: model description. *Journal of Nutrition* 122: 2239-2256.

Doornewaard, G.J., A.C.G. Beldman and C.H.G. Daatselaar (2002), Trend analysis 1997-2001. In: Anonymus, Resultaten melkvee 2001. Praktijkcijfers 2, Houten, pp. 31-47 (In Dutch)

Erisman, J.W. (2000), The flying ghost, ammonia from agriculture and the consequences for nature. BetaText, Bergen, 271 pp. (In Dutch)

European Community (1991), 91/676/EEG: Guidelines of the Council of 12 December 1991 with respect to the protection of water against pollution by nitrates from agricultural sources. European Community, Brussels, pp 1-8.

Ferguson, J.D. (2001), Milk urea nitrogen. http://cahpwww.nbc.upenn.edu/mun/mun.html, 15/11/2003.

Groen, A.F., K. de Groot, J.D. van der Ploeg and D. Roep (1993), Breeding in style, a preliminary study of the relation between socio-economic diversity and farm-specific breeding objectives. Bedrijfsstijlenstudie No. 9, Vakgroep Veefokkerij en Vakgroep Rurale Sociologie, Landbouwuniversiteit Wageningen, Wageningen. 35 pp. (In Dutch)

Henkens, P. and H. van Keulen (2001), Mineral policy in the Netherlands and nitrate policy within the European Community. *Netherlands Journal of Agricultural Science* 49: 117-134.

Jarvis, S.C., D. Scholefield and B.F. Pain (1995), Nitrogen cycling in grazing systems. In: Nitrogen Fertilization in the Environment. P.E. Bacon (Ed.), New York, Marcel Dekker Inc.: pp. 381-419.

Jonker, J.S., R.A. Kohn and R.A. Erdman (1998. Using milk urea nitrogen to predict nitrogen excretion and utilization efficiency in lactating dairy cows. *Journal of Dairy Science* 81: 2681-2692.

Kauffmann, A. J. and N.R. St-Pierre (2001), The relationship of milk urea nitrogen to urine nitrogen excretion in Holstein and Jersey cows. *Journal of Dairy Science* 84: 2284-2294.

Kebreab, E., J. France, R.E. Agnew, T. Yan, M.S. Dhanoa, J. Dijkstra, D.E. Beever and C.K. Reynolds (2003), Alternatives to linear analysis of energy balance data from lactating dairy cows. *Journal of Dairy Science* 86: 2904-2913.

Keulen, H. van, H.G. van der Meer and J.M. de Boer (1996), Nutrient balances of livestock production systems in the Netherlands. In: Utilization of Local Feed Resources by Dairy Cattle: Perspectives of Environmentally Balanced Production Systems. Proceedings of a Symposium of the Wageningen Institute of Animal Sciences, Wageningen, pp. 3–18.

Külling, D.R., H. Menzi, T.F. Kröber, A. Neftel, F. Sutter, P. Lischer, and M. Kreuzer (2001), Emmisions of ammonia, nitrous oxide and methane from different slurry types of dairy manure during storage as affected by dietary protein content. *Journal of Agricultural Science* 137: 235-250.

Langmeier, M., A. Oberson, M. Kreuzer, P. Mäder, D. Dubois and E. Frossard (2002), Nitrogen fertilizer value of cattle manure applied on soils originating from organic and conventional farming systems. *Agronomie* 22: 789--800.

Lantinga, E.A. and J.C.J. Groot (1996), Optimization of grassland production and herbage feed quality in an ecological context. In: A.F. Groen and J. van Bruchem (Eds), Utilisation of Local Feed Resources by Dairy Cattle, EAAP Publication no. 84, Wageningen Press, Wageningen. pp 58-66.

Lantinga, E.A. and H.H. van Laar (1997), Renaissance of mixed farming: a road to sustainability: business and research plan of two mixed farms on Ir. A.P. Minderhoudhoeve. Landbouwuniversiteit Wageningen, Wageningen. 90 pp. (In Dutch)

Meer van der, H.G., R.B. Thompson, P.J.M. Snijders and J.H. Geurink (1987), Utilisation of nitrogen from injected and surface-spread cattle slurry applied to grassland. In: H.G. Van der Meer (Ed.), Animal Manure on Grassland and

Fodder Crops: Fertilizer or Waste? Martinus Nijhoff Publishers, Dordrecht, pp. 47–71.

Monteny, G.J. (2001), Modelling of ammonia emissions from dairy cow houses. Wageningen University, Wageningen, 156 pp.

Mooij, M. (1996), Composition of animal manure. *Meststoffen* 1996: 38-41 (In Dutch).

Muller, B. (1999), De stikstofgift kan ongestraft een stuk omlaag. *Boerderij/ Veehouderij* 84 no. 3, 12-13.

Oenema, J., G.J. Koskamp and P.J. Galama (2001), Guiding commercial pilot farms to bridge the gap between experimental and commercial dairy farms; the project 'Cows and Opportunities'. *Netherlands Journal of Agricultural Science* 49: 277-296.

Oenema, O., F.A. Wopereis and G.H. Ruitenberg (1992), Developing new recommendations for nitrogen fertilisation of intensively managed grassland in the Netherlands. *Aspects of Applied Biology* 30: 249-253.

Oenema, O., P.C.M. Boers, M.M. van Eerdt, B. Fraters, H.G. van der Meer, C.W.J. Roest, J.J. Schröder and W.J. Willems (1998), Leaching of nitrate from agriculture to groundwater: the effect of policies and measures in the Netherlands. *Environmental Pollution* 102: 471-478.

Oomen, G.J.M., E.A. Lantinga, E.A. Goewie and K.W. van der Hoek (1998), Mixed farming systems as a way towards a more efficient use of nitrogen in European Union agriculture. *Environmental Pollution* 102: 697-704.

Phillips, V.R., D.A. Cowell, R.W. Sneath, T.R. Cumby, A.G. Williams, T.G.M. Demmers and D.L. Sandars (1999), An assessment of the way to abate ammonia emissions from UK livestock buildings and waste stores. Part 1: ranking exercise. *Bioresource Technology* 70: 143-155.

Ploeg van der, J.D. (2000), Revitalising agriculture: farming economically as a starting ground for rural development. *Sociologica Ruralis* 40 (4), pp. 497-511.

Ploeg, J.D. van der (2003), The Virtual Farmer, Van Gorcum, Assen, 432 pp.

Ploeg, J.D. van der, F.P.M. Verhoeven, H.Oostindië and J. Groot (2003), What does it amount to? An explorative analysis of farm economic and agronomic data of VEL and VANLA farms. Onderzoeksrapport VEL and VANLA fase 2. Wageningen University, Wageningen, 56 pp. (In Dutch).

Portela, E. (1994), Manuring in Barroso: a crucial farming practice. In: J.D. van der Ploeg and A. Long (Eds), *Born From Within, Practice and Perspectives of Endogenous Rural Development*, Van Gorcum, Assen. pp. 59-70.

Reijneveld, J. A., B. Habekotté, H.F.M. Aarts and J. Oenema (2000), 'Typical Dutch'. View on the variability within Dutch dairy farming. Research Station for Cattle, Sheep and Horse Husbandry (PR), Lelystad. 83 pp (In Dutch).

Reijs, J.W., W.H. Meijer, E.J. Bakker and E.A. Lantinga (2003), Explorative research into quality of slurry from dairy farms with different feeding strategies. *NJAS Wageningen Journal of Life Sciences* 51-1/2: 67-90.

Rip, A. and R. Kemp (1998), Technological Change. In: S. Rayner and E.L Malone (Eds), *Human Choice and Climate Change,* Columbus, Ohio: Battelle Press, Volume 2. pp 327-399.

Roep, D., J.D. van der Ploeg and J.S.C. Wiskerke (2003a), Managing technical-institutional design processes: some strategic lessons from environmental co-operatives in the Netherlands. *NJAS Wageningen Journal of Life Sciences* 51-1/2: 195-217.

Roep, D., K.J. van Calker, S. de Rooij, F. Verhoeven and A. Wolleswinkel (2003b), A country full of ideas; from renewal in practice to system innovation in dairy farming by smart experimentation. Information Research Project 'Innovative dairy farmers', Wageningen University and Research Centre. 4 pp (in Dutch).

Schiere, J.B. and J. Grasman (1997), Agro-ecosystem health: aggregation of systems in time and space. In: J. van Bruchem (Ed.), Agro-ecosystem Health. National Council for Agricultural Research, The Hague. pp. 23-36.

Silgram M. and B.J. Chambers (2002), Effects of long-term straw management and fertiliser nitrogen additions on soil nitrogen supply and crop yields at two sites in eastern England. *Journal of Agricultural Science, Cambridge* 139: 115–127.

Smits, M. C. J., H. Valk, A. Elzing and A. Keen (1995), Effect of protein nutrition on ammonia emmision from a cubicle house for dairy cattle. *Livestock Production Science* 44: 147-156.

Soest, P.J. van (1994), Nutritional Ecology of the Ruminant. Cornell University Press,. 476 pp.

Stuiver, M., J.D. van der Ploeg and C. Leeuwis (2003), The VEL and VANLA environmental co-operatives as field laboratories. *NJAS Wageningen Journal of Life Sciences* 51-1/2: 27-40.

Swagemakers, P. (2002), Making differences: novelty-production and the contours of a local co-operative. Studies van landbouw en platteland no. 33, Wageningen University, Wageningen, 239 pp. (In Dutch)

Tamminga, S., W.M. van Straalen, A.P.J. Subnel, R.G.M. Meijer, A. Slag, G.J.G. Wever and M.C. Blok (1994), The Dutch protein evaluation system: the DVE/OEB system, *Livestock Production Sciences* 40: 139-155.

Tamminga, S. (1995), Energy and protein supply and performance of dairy cows. In: L. Babinszky, (Ed.), Proceedings of 4th International Symposium on Animal Nutrition, 17 october 1995, Pannon Agricultural University, Kaposvár, Hungary. pp. 99-112.

Tamminga, S. (1996), A review on environmental impacts of nutritional strategies in ruminants. *Journal of Animal Science* 74: 3112-3124.

Tamminga, S. and A.M. van Vuuren (1996), Physiological limits of fibrous feed intake and conversion in dairy cows. In: A.F. Groen and J. van Bruchem (Eds), Utilisation of Local Feed Resources by Dairy Cattle, EAAP Publication no. 84, Wageningen Press, Wageningen. pp 19-33.

Tamminga, S., J. van Bruchem and T. Wensing (1999), The role of nutrition management in the control of environmental pollution. In: Production Diseases in Farm Animals: 10th International Conference 1998, Wageningen Pers, Wageningen. pp. 270-281.

Velthof, G.L., A. Bannink, O. Oenema, H.G. van der Meer, and S.F. Spoelstra (2000), Relationships between animal nutrition and manure quality: A literature review on C, N, P and S compounds. Alterra, Wageningen. 44 pp.

Verhoeven, F. P. M., J. van Bruchem and G.M.J.H. van der Made (1998), Stikstof in Balans; cijfers van 100 Friese melkveebedrijven tonen belang bodembenutting. *Veeteelt*, April 2: pp. 496-498 (In Dutch).

Verhoeven, F.P.M., J.W. Reijs and J.D. van der Ploeg (2003), Re-balancing soil-plant-animal interactions: towards reduction of nitrogen losses. *NJAS Wageningen Journal of Life Sciences* 51-1/2: 147-164.

Vuuren, A.M. van and J.A.C. Meijs (1987), Effects of herbage composition and supplement feeding on the excretion of nitrogen in dung and urine by grazing dairy cows. In: H.G. Van der Meer (Ed.), Animal Manure on Grassland and Fodder Crops: Fertilizer or Waste? Martinus Nijhoff Publishers, Dordrecht, pp. 17-25.

Waltner-Toews, D. (1997), Agro-ecosystem health: Concepts and principles. In: J. van Bruchem (Ed.), Agro-ecosystem health. National council for agricultural research, The Hague. pp. 9-22.

Notes

1 The calculations of NUE are apparent ones based on the N content of products divided by N inputs. Other inputs of N through biological fixation and atmospheric deposition are not taken into account, unless indicated otherwise.

2 This required a 50 per cent reduction of 1985 levels of nitrogen emissions from agriculture to surface water.

3 This sample covered Frisian farms larger than 45 hectares with an output of more than 12,500 kg ha $^{-1}$

4 The art of fine-tuning also involves the wide range of growth factors involved in agricultural production processes. Because of the mutual improvement of resources, as well as the mutual adjustment of relevant growth factors, specific, endogenous development trajectories and potentials are emerging and being sustained.

5 Wageningen University and Research Centre.

6 DVE stands for Darm Verteerbaar Eiwit or true protein digested in the small intestine, for a full description see (Tamminga *et al.* 1994)

7 The number of farms in the tables varies. This is a result of the inaccuracy of some data. Farms with inaccurate data in one year are not presented.

8 OEB stands for Onbestendig Eiwit Balans or degraded protein balance, for a full description see (Tamminga *et al.* 1994)

9 VEM stands for Voeder Eenheid Melk. Dutch standard for Net Energy lactation (1 VEM = 6.9 kJ)

10 Urea is formed from ammonia in the kidney and liver. Ammonia is produced by the breakdown of protein in the rumen and by the ruminant tissues and is very toxic, whereas urea is non-toxic. The conversion of ammonia to urea prevents ammonia toxicity. Urea diffuses readily from blood into milk. It is a normal constituent of milk and the measure of this can be used to estimate the concentration of blood urea. Urea concentrations in blood and in milk are influenced by protein intake, energy intake and urinary excretion.

11 In the Netherlands milk urea content is used instead of MUN. 1 mg MUN is equal to 2.14 mg urea.