A mathematical approach to comparing environmental and economic goals in dairy farming on sandy soils in the Netherlands

G.W.J. van de Ven

Stellingen

1. De bewering van de Wit c.s. dat de eerste optimaliseringsronde met IMDP per definitie voor elke doelrestrictie de meest ongunstige waarde die je hoeft te accepteren oplevert, is onjuist.

   (Wit, C.T. de, H. van Keulen, N.G. Seligman & I. Spharim,1988. Agric. Sys. 26,211-230; dit proefschrift)

2. Het N-overschot op melkveebedrijven is geen goede maatstaf voor de mate waarin aan de emissienormen voor ammoniak en nitraat wordt voldaan, doordat het aandeel van ammoniak- en nitraatverliezen in het N-overschot sterk bepaald wordt door de bedrijfsopzet.

   (Dit proefschrift)

3. Regionale differentiatie van de normen voor ammoniakvervluchtiging en nitraatuitspoeling kan een groot deel van de boeren meer perspectieven voor bedrijfsontwikkeling bieden, zonder extra milieuschade te veroorzaken, dan één algemene norm.

4. Bij het ontwikkelen van landbouwproduktiesystemen kan de methode prototypering doelgerichter worden toegepast als vooraf een analyse met IMDP plaats vindt.

   (Vereijken, 1992. Neth.J.Agric.Sci. 40, 209-224 ; dit proefschrift)

5. Toepassing van IMDP bij het ontwikkelen en analyseren van regio-specifieke bedrijfstypen kan een constructieve bijdrage leveren aan kennisimplementatie en plattelandsvernieuwing.

6. Het overheidsbeleid gericht op het kennisintensiever maken van de landbouwpraktijk is inconsistent met de zware bezuinigingen op het gebied van het genereren en toepasbaar maken van nieuwe kennis.

7. Het voortdurend reorganiseren van instituten leidt tot navelstaren en een inefficiënte inzet van duur personeel.

8. Het is onwaarschijnlijk dat de continuïteit van kennisinstellingen gewaarborgd kan worden zonder de instroom van jong talent.

9. Het opleiden van academici zonder uitzicht te bieden op een passende baan is een sociaal onaanvaardbare inzet van middelen.

10. Het veelvuldig voorkomen van nevenfunkties in leidinggevende banen suggereert dat dergelijke banen ook met zorg voor kinderen gecombineerd zouden kunnen worden.

G.W.J. van de Ven

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Abstract

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A Dairy Farming Model was developed to screen the potentials for development of dairy farming on sandy soils in the Netherlands with respect to environmental, agro-technical and economic demands. The Dairy Farming Model consists of technical coefficient generators (TGC models) and an interactive multiple goal linear programming model (IMGLP model). The TCG models have been used to quantify input-output coefficients for a wide range of production techniques for grass, maize, fodder beet and milk. The results of the TCG models have been used in the IMGLP model, that optimizes the set of production techniques with respect to the goals defined.
The model has been applied to a fictitious region with sandy soils. The analysis shows that dairy farming can meet both economic and environmental goals, as set by the government for the year 2000. However, this requires a reduction in labour income. Many different dairy farming systems are possible. A few general characteristics are: low N application on grazed grassland, a large proportion of the animals housed in low-emission stables and a substantial part of the concentrates produced in the region itself.
Application of the Dairy Farming Model to the situation at the experimental dairy farm 'De Marke' has shown that the model is suited for exploring the opportunities for the development of dairy farming at a specific location, provided it can be initialized for that situation. Initial farm lay-out and measures taken at 'De Marke' have been evaluated.

Additional keywords: grassland, maize, fodder beet, environment, economics, landscape, nitrogen, phosphorus, modelling, linear programming

Voorwoord

Het in dit proefschrift beschreven onderzoek is midden 1987 gestart als een 'FOMA-project': Optimalisering van ruwvoederproduktie en gebruik van dierlijke mest in relatie tot milieu-eisen. Daarna is het als intern AB-project voortgezet.
Mijn promotoren prof. dr. ir. H. van Keulen en prof. dr. ir. J.A. Renkema bedank ik voor hun begeleiding. Jan, zonder de technische aspecten uit het oog te verliezen, plaatste jij met jouw economische invalshoek dingen vaak in een ander perspectief dan ik gewend was. Dit heeft voorkomen dat het bij een puur technische analyse is gebleven. Herman, jouw enthousiasme en vertrouwen zowel in het werk als in mij, zijn erg stimulerend geweest. Ik ben je zeer erkentelijk dat je de taak van wijlen prof.dr.ir. C.T. de Wit, die de afronding van dit proefschrift helaas niet meer mee heeft mogen maken, over hebt willen nemen. Gedurende de eerste jaren van het werk aan het proefschrift heeft Kees mij vanuit de vakgroep Theoretische Productie- ecologie met veel gedrevenheid en aandacht begeleid.
Hugo van der Meer bedank ik voor zijn begeleiding, zijn kritische commentaar en zijn nimmer aflatende steun om dit proefschrift af te ronden.
Met Jan Schans heb ik vele inspirerende discussies gevoerd over de opzet van het LP-model. Zijn hulp bij het oplossen van problemen met de software was onontbeerlijk. Eltje Boons-Prins heeft een substantiële bijdrage geleverd aan kwantificering van technische coëfficiënten voor het houden van jongvee en de teelt van maïs. Jaap Schröder heeft resultaten van maïsproeven beschikbaar gesteld en was bereid mee te denken bij definiëring van de teelttechnieken voor maïs. Ben Rutgers heeft met veel enthousiasme de figuren voor dit proefschrift gemaakt. Rina Kleinjan-Meijering heeft op inventieve wijze figuren en tekst aan elkaar gekoppeld en voor de lay-out zorg gedragen. Aan al deze mensen: hartelijk dank.
Verder bedank ik alle collega's van de afdelingen Agrosysteemkunde, waar het eerste deel van het proefschrift werd uitgewerkt, en Grasland en Vegetatiekunde, waar het proefschrift werd voltooid, voor hun collegialiteit en belangstelling voor mijn werk.

Contents

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1. Introduction and problem definition

1.1. From CAP to integrated agriculture

Agricultural development is guided by technical and socio-economic developments and by the objectives that are pursued. In past decades, the aim of the Common Agricultural Policy (CAP) of the European Union (EU) was to increase production volumes to the level of self sufficiency, increase agricultural productivity, maintain low and stable consumer prices for basic food commodities and provide a parity income at farm level (Meester, 1980). This policy allowed for the rapid implementation of newly developed farming techniques. To reach these objectives an active market and price policy was pursued. However, high investment costs, increasing labour costs and greater knowledge requirements led to specialization and the separation of arable farming and animal husbandry.

Adverse effects also occurred: excess production, high intervention costs and specific problems arose in each sector. In arable farming a greater dependence on pesticides developed, while the high input rates could not prevent increased population levels of many pests and the increased incidence of many diseases. Intensive pig farming resulted in low prices and a high P surplus with the associated environmental pollution and in dairy farming a large N surplus was created accompanied by environmental problems (Vereijken, 1992).

The CAP's focus on a limited number of goals has led to the over-achievement of some of these goals and the neglect of other agricultural land use goals (De Wit, 1988). In response to these problems, the concept of integrated dairy farming was developed. It is defined as a sustainable, technically highly-developed form of agriculture, which, compared with current agricultural practices, uses less energy and other resources, limits environmental pollution, provides more employment, provides a return on labour and capital at parity with other sectors in society and, in addition to agricultural products, produces an attractive landscape (Netherlands Scientific Council for Government Policy, 1984). Integrated agriculture defines a framework for the optimization of agricultural production systems. Not all the objectives may be reached to the same extent at the same time, but they serve as a guideline for development.

The aim of this study is to explore development options and identify promising techniques in dairy farming from both the environmental and economic point of view in the context of integrated dairy farming.

1.2. Environmental problems

Nitrate leaching occurs when part of the nitrate present in the rooted zone is not taken up by the crop but transported to lower layers by excess rainfall. The amount of N leached depends on soil type, depth of the ground-water table and land use. In the upper meter of the ground-water in sandy soils in the Netherlands, which are the most sensitive to leaching, the nitrate concentration under arable crops is, on average 45-70 mg N l^{-1}, under maize 110 and under grass 25. However, there is a wide variation in the measured values (Van Duijvenbooden, 1989). Nitrate concentration decreases with increasing depth, but increases at all depths with the course of time. The EU norm for nitrate in drinking water is 11.3 mg N l^{-1} at 2 m below the ground-water table. At only 2 of the 69 phreatic ground-water wells for drinking water this norm was exceeded in 1988. However, it is expected that about 70 and 50 % of the water, in the eastern and southern sandy regions respectively, will contain too much nitrate by the year 2000. This is 13 % of the total phreatic ground-water used for drinking water (Van Duijvenbooden, 1989).

It depends very much on the local circumstances how much of the nitrate transported to below the rooted zone contributes to ground-water pollution. Nitrate can be reduced to dinitrogen oxide and nitrogen gas, both in the unsaturated and in the saturated zones of the soil when organic matter or iron sulphides are present. The half-life time of nitrate under the influence of organic matter is 0.25-1.5 years and under the influence of iron sulphides 0.-4.5 years. As the transport rate of nitrate in the soil is 1 m yr^{-1} on average, this is well within the time required to reach the depth of water withdrawal (Van Beek, 1987). This agrees with the observation that either hardly any nitrate is found at the depth of withdrawal or relatively high concentrations are measured, when no iron sulphides or organic matter are present. At the highest nitrate concentrations the rate of increase is also greatest (Van Duijvenbooden, 1989). Nitrogen gas is not a pollutant, but dinitrogen oxide contributes to the greenhouse effect.

In 1993 deposition of potentially acidifying compounds, i.e. SO_x, NO_x and NH_y, was estimated at 4 280 mol H^+ ha^{-1} on average in the Netherlands (Heij & Schneider, 1995). The most serious damage by acidification can be prevented at a deposition level of 1 400 mol ha^{-1} (Min. of Housing, Spatial Planning and Environment, 1989). The share of SO_x, NO_x and NH_y in the total acidic deposition was 36 %, 18 % and 46 %, respectively. SO_x is mainly emitted by refineries and electricity companies, 50 % of the NO_x is emitted by road traffic and 92 % of the NH_y emission, i.e. 19 million kg NH_3, originates from agricultural practices. In 1993 cattle was responsible for 52 % of the ammonia emission in the

Netherlands. In 1993 N deposition in both NO_x and NH_y was 38 kg ha^{-1} on average, but there are large regional differences (Lekkerkerk et al., 1995).
Deposition of ammonia leads to N enrichment and acidification of the soil. In weakly buffered ecosystems, such as heath lands, many characteristic species disappear and fast growing grass species take over due to the increased N availability. In forest ecosystems on nutrient poor soils, increased N content in leaves and needles lead to the greater susceptibility of trees to stress factors, such as drought, frosts and fungal diseases (Berendse et al., 1988; Roelofs et al., 1987). Soil acidification results in the reduced vitality of trees due to plant toxic Al^{3+} levels in the soil (Langeweg, 1989).
P in surface waters leads to eutrification and excessive growth of algae. P accumulation in the soil in itself is not a problem, but as soon as the soil is saturated with P, leaching occurs. This occurs, when more than 25 % of the phosphate binding capacity of the soil is used (Van der Zee et al., 1990). P saturation has been observed over a large area of the sandy regions, especially those areas under continuous maize cultivation (Breeuwsma & Berghs, 1993).
Due to the extensive land and water development projects implemented since the beginning of this century, largely for the benefit of agriculture, the structure of the landscape has changed from a diverse small scale structure into a more uniform large scale one. In many places wooded banks have disappeared and rivers have been canalized (Min. of Agriculture, Nature Management and Fisheries, 1989; De Wit, 1988).

1.3. Characteristics and problems of dairy farming in the Netherlands

Dairy farming is an important sector in Dutch agriculture, contributing 40 % of the total added value. It also contributes to employment, especially when associated industrial activities are considered, and to the balance of trade (Veeneklaas, 1990).
The continuing intensification in dairy farming has led to excess milk production. Between 1970 and 1983, average milk production per ha grassland and fodder crops increased by 286 kg yr^{-1} (Figure 1.1) and total milk production increased from 8.25 to 13.20 million tonnes yr^{-1}.
In 1983 milk surpluses in the EU were estimated at 24 % of the marketed production (Van der Meer & Wedin, 1989). Therefore, milk quota were implemented, resulting in both a lower production per hectare and a lower total production (11.0 million tonnes in 1993). Production per cow, however, continued to increase, as a result of selection for the most productive animals

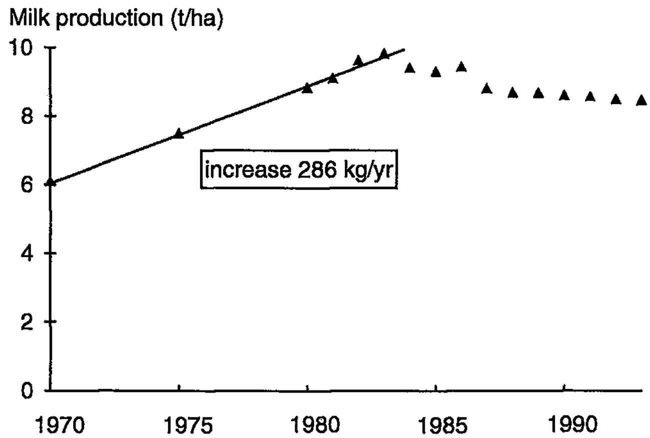

Figure 1.1 Average milk production in t ha^{-1} between 1970 and 1993 (Source: Agricultural Economics Research Institute & Netherlands Central Bureau for Statistics, 1975-1995).

and technical progress, from 5 090 kg fat and protein corrected milk per cow per year in 1980 to 6 730 in 1993. This resulted in a decrease in the average stocking rate from 1.9 cows per ha grassland and fodder crops in 1983 to 1.3 in 1993. In 1993 there were 32 800 specialized dairy farms in the Netherlands, which amounted to about 27 % of the total number of farms. About 90 % of dairy cows, i.e. 1.57 million, were found on these farms, hence each farm had on average 48 cows (Agricultural Economics Research Institute & Netherlands Central Bureau for Statistics , 1989, 1995).

Dairy farming contributes significantly to environmental pollution and has a serious impact on the nature and landscape. The problems are mainly caused by imbalanced nutrient cycles. An analysis of the nutrient balance of current dairy farms for 1991/1992 shows that only 80 kg ha^{-1} yr^{-1}, or 17 % of the N imported into the production system, leaves the farm in agricultural products (Table 1.1; Aarts & Middelkoop, 1994). Milk is the main output, accounting for about 80 %, while inorganic fertilizers and concentrates comprise 80 % of the total inputs of 487 kg ha^{-1} yr^{-1}. The N surplus, if not accumulated in the soil or denitrified to elementary N, constitutes a potential source of environmental problems, in the form of nitrate leaching, emissions of nitrous oxides, ammonia volatilization and run off.

For phosphorus and potassium the surplus is 29 and 84 kg ha^{-1} yr^{-1}, respectively. Phosphorus (P) is far less mobile than nitrogen and leaching only occurs after the soil is saturated. Potassium (K) can be adsorbed by clay particles and organic matter. On sandy soils the content of both clay particles and organic matter is low and K is easily leached to the ground-water.

Table 1.1 Nutrient balances of specialized Dutch dairy farms in 1991/1992 per ha grassland and fodder crops in kg ha^{-1} yr^{-1}.

INPUTS	N	P	K	OUTPUTS	N	P	K
Inorganic fertilizers	275	14	10	Milk	66	11	18
Concentrates	113	21	57	Meat	14	4	1
Atmospheric deposition	49	1	4				
Purchased roughage	15	2	15				
Sundries	35	6	17				
				Surplus (input-output)	406	29	84
Total	487	44	103		487	44	103

1.4. Towards integrated dairy farming

Society no longer accepts the degradation of the natural resources and demands the development of sustainable production systems, which take into account objectives like the environment, landscape and nature.

1.4.1. Policy goals

The objectives for nature and landscape have been formulated in the Nature Policy Plan (Min. of Agriculture, Nature Management and Fisheries, 1989). A national ecological network has been designed throughout the Netherlands. Specific policy goals for nitrate leaching and ammonia volatilization have been laid down in the National Environmental Policy Plan (Min. of Housing, Spatial Planning and Environment, 1989).

The EU norm for drinking water has been converted into a norm for ground-water of 50 mg nitrate at 2 m below the ground water table, assuming that below this level no denitrification occurs. In areas where ground-water is used for drinking water purposes, this maximum concentration has to be reached by the end of the year 2000. At a ground-water recharge of 300 mm per year this amounts to leaching losses of 34 kg N ha^{-1} yr^{-1}.

In 1980, total ammonia emissions in the Netherlands amounted to 250 million kg. This represents about 100 kg N ha^{-1} grassland and fodder crops (Agricultural Economics Research Institute & Netherlands Central Bureau for Statistics, 1983; Lekkerkerk et al., 1995). By 2000 a reduction of 70 % has to be realized and by 2010 a reduction of 80 - 90 %, resulting in a target emission of 30 kg N ha^{-1} yr^{-1} in 2000 and 10-20 kg N in 2010.

For run off a general water quality goal has been defined. In stagnant fresh waters N concentration has to be below 2.2 mg l^{-1} during the summer period. Furthermore, N contamination of the North Sea has to be reduced by 50 % in 1995 compared with 1985. Therefore, the N emissions of households, industry and agriculture have to be reduced by 70 % during that period (Min. of Transport, Public Works & Water Management, 1989). This is difficult to convert to a norm per ha in dairy farming and it is assumed that if other losses are limited, run off will also be reduced.

In surface waters, maximum P concentration has been set to 0.15 mg l^{-1} to prevent excessive growth of algae. No separate norm has been set for phosphate leaching. If the norm for surface water is translated to ground-water, phosphorus leaching losses are limited to 0.5 kg ha^{-1}. No norm has been set for phosphor surplus either, but by the year 2000 the amount of phosphorus applied will be limited to the amount transported in products.

The question is how those objectives can be achieved and what sacrifices have to be made on the production objectives. There may be scope for meeting all objectives to a large extend, as the additional objectives have never received serious attention before (Aarts et al., 1992; Vereijken, 1992; Netherlands Scientific Council for Government Policy, 1984). However, it is not clear what the scope for development of dairy farming is, if all these objectives are taken into consideration, without giving priority to current production-oriented objectives.

1.4.2. Elements essential to environmentally-sound dairy farming

Integrated dairy farming aims to create a balanced situation (Section 1.1) and provides a framework in which various goals can be considered in the light of socio-economic and environmental aspects. To explore the possibilities of integrated dairy farming all the relevant technical elements have to be quantified. Together they form a rather complicated network, so it is difficult to include all objectives from the outset. Therefore, those objectives which need attention most urgently have been selected and expanded upon in this study. In dairy farming, these objectives concern minimizing ammonia volatilization, nitrate leaching and P surplus, maximizing labour income, developing an attractive landscape and preventing a manure surplus. These objectives will be further elaborated on below.

Various elements in the dairy farming system are pivotal to development of environmentally-sound practices. Inorganic fertilizers constitute a large part of the N input in dairy farming (Table 1.1). N supply and N demand have to be balanced, both in time and in space to prevent unnecessary losses. When inorganic fertilizer is applied, nitrate leaching is the major loss process. When

animal manure is applied, ammonia volatilization also occurs, the amount depending on the application method.
The decision to cut grass, have it grazed or a combination of both influences the total herbage yield and the amount and type of N losses. Grazing leads to high leaching losses and zero grazing to high volatilization losses.
Crop production, the quality of the fodder and N losses associated with the cultivation method, vary among crops.
Concentrates contribute substantially to the N input in dairy farming (Table 1.1). By substituting concentrates with high quality forage, P and N surplus and N losses may be reduced, if the fertilizer input need not be increased too much.
At a higher milk production level per cow, relatively less energy is required for maintenance and a larger proportion is converted into milk.
Nitrate leaching from maize land is usually higher than from grassland, but this is at least partly associated with current cultivation practices. By growing a catch crop, such as Italian rye grass or rye, N present in the soil profile in autumn can be taken up and leaching during the winter may be partly prevented.
Surface application of slurry leads to high ammonia emissions and a low N availability to the crop. Incorporating the slurry in the soil almost doubles the N available to the crop and greatly reduces ammonia volatilization (Wadman, 1988; Mulder & Huijsmans, 1994).
To design environmentally-sound dairy farming systems, all these pivotal aspects need to be taken into account.

1.4.3. Scope of the study

Dairy farming consists of a plant production part and an animal production part, both with its own specific environmental effects. The emphasis of this study is on forage production and utilization on dairy farms. In addition to the objectives mentioned above, forage should provide livestock with sufficient fodder of a quality commensurate with the desired milk production level and absorb all manure produced by the animals. To evaluate the impact of a certain measure or production technique or a combination of several ones, the complete dairy farming system has to be considered, because the transfer of adverse effects from one part to another part of the system should be avoided.
The relationship between crop production and fertilizer application varies among soil types, hydrological situation and weather conditions. The dairy farming system, which is optimally adapted to the prevailing conditions, will thus vary for different regions. The present study is focused on one specific situation. However, the framework has been defined in such a way that it can easily be extended to other situations. Almost half the grassland in the

Netherlands is situated on sandy soils (Agricultural Economics Research Institute & Netherlands Central Bureau for Statistics, 1990), where environmental problems are most pronounced. Therefore, a sandy soil with a good water-holding capacity, in order to prevent severe yield reductions due to drought periods, has been considered.
The contribution made by dairy farming to the national N surplus is rather large, while the P and K surpluses are mainly caused by intensive animal husbandry ('t Jong et al., 1989). The N cycle in dairy farming has been worked out in most detail. For P, the feeding standard has been applied and the balance calculated to ensure that the P supply is adequate, but does not exceed legal limits.
In dairy farming the main fodder crops are grass and silage maize, so these crops have been included. Fodder beets and ground ear silage have been selected as examples of concentrate feed that can be grown on the farm. This may reduce the amount of concentrate that has to be purchased from outside.
In addition to technical relationships, economic ones are also taken into account. In standard farm economic analysis the farm is the essential unit and scale effects are taken into account explicity (Wossink, 1993; Berentsen & Giessen, 1995; Hennen, 1995). The usual farm economic analysis has been adapted by converting fixed costs to variable costs to prevent scale effects (Chapter 5). Behavioural relationships have been omitted.

1.5. System analysis in dairy farming

Economists and agronomists each approach agricultural development from their own specific point of view, using their own language and research tools. Their approaches are generally so different that often communication and exchange of data is difficult. However, to obtain a realistic picture of the potential for agricultural development, taking into account technical as well as economic aspects, both approaches should be integrated.
Often, different technically feasible development paths are possible in which different goals are realized to a greater or lesser extent and the 'trade-offs' between the various goals determine the degree of compromise that can be reached. The development plan that is finally selected and implemented reflects, implicitly or explicitly, the relative importance attached to the various goals. All possible environmental and economic goals aimed at, and constraints imposed on dairy farming should be taken into account simultaneously to arrive at a satisfactory production system. Therefore, the problem has been defined mathematically as an optimization problem with multiple goals (Nijkamp & Spronk, 1980).

1.5.1. Methodology: Interactive Multiple Goal Linear Programming (IMGLP)

The approach used in this study is aimed at filling the gap between technical and economic analyses. By using input-output tables as a starting point, a common technique in economics, the results of the technical analyses are presented in a way that facilitates their use by economists and policy-makers.

To investigate the various options, Interactive Multiple Goal Programming (IMGLP) was used as an optimization technique. IMGLP is a multi-criteria decision method, that can easily be combined with linear programming (Spronk and Veeneklaas, 1982). The various goals are optimized for a mix of production techniques subject to a set of constraints. The production techniques are defined by quantifying their intended and unintended outputs and their required inputs. The inputs utilize resources that are limited and may therefore be constraining for the selection of production techniques.

The degree to which a goal is realized is expressed by its value in the optimization procedure. In each iteration cycle each of the goals is optimized individually, while restrictions are imposed on the values of the other goal variables. A goal restriction represents an acceptable value of a goal variable. By tightening the goal restrictions in successive iteration cycles, i.e. improving the least favourable values for the goal variables, the feasible area is reduced and, in general, so are the best attainable values of the other goals. During the process, the model user can express preferences and become aware of the costs of more fully realizing one goal in terms of the others. Finally, a situation is reached where it becomes impossible to improve on any of the goals, without sacrificing one or more of the others. The result is a feasible combination of the values of the goal variables, and the associated mix of production techniques (Veeneklaas, 1990). For a more detailed description of IMGLP and its use in agricultural planning, see Van Keulen en Van de Ven (1988) and De Wit et al. (1988).

All formulated production techniques should be technically feasible, but that does not mean that they have to be practised on farms at the moment. They may still be in the research and development pipeline or they may not have been implemented due the dominance of economic goals over environmental ones, so far.

It is, however, important to consider all possible production techniques that could offer opportunities for the future, i.e. it is necessary to avoid any bias towards a particular production technique, so that no prospects for development are ruled out in advance. Quantification of production techniques that are not yet practised, in terms of inputs and outputs, may be difficult due to a lack of detailed information, but then it is preferable to make a best possible estimate rather than to omit them. Priorities for research and development can be derived from the selected set of production techniques in the optimal plan.

1.5.2. Structure of the Dairy Farming Model

A dairy farming system can be described in terms of various characteristics. It depends on the goals to be optimized which characteristics need to be quantified. The characteristics of the production techniques for grass, maize and fodder beet are listed in the first column of Figure 1.2. They represent the essential elements referred to in Subsection 1.4.2. For each of these characteristics several values can be set by the user of the model. For instance, N application rate on grassland can be set to any value between 100 and 450 kg ha^{-1} yr^{-1}.

The input-output table should be quantified consistently for the whole range of production techniques for the various crops. Therefore, technical coefficient generators (TCG models) have been developed. The values of inputs and outputs for a production technique are called technical coefficients. GRASMOD is a TCG that calculates inputs and outputs for a wide range of grass production and utilization techniques. Inputs are land and fertilizer for instance and outputs are forage and nitrate leaching (Figure 1.2). The structure of GRASMOD and the relations and data used in the model are described in Chapter 2 of this thesis. GRASMOD can also be used independently to examine the effects of grassland management and fertilizer regime on grass and milk production and on N and P emissions to the environment (Chapter 3). For maize and fodder beets separate TCG models have been developed, taking into account other characteristics, as cultivation practices differ from those for grass. The type of inputs and outputs is similar. Both, the structure and the results of the TCG models for maize and fodder beet are described in Chapter 4.

In addition to the input-output table for crop production techniques, some other technical and economic data are required. These are supplied to the model by means of a data file (Figure 1.2). Inputs and outputs for cattle are taken into account partly in GRASMOD and partly in the data file. For cattle, forage is an input and milk and meat are outputs. The IMGLP model integrates the input-output table of the production techniques and the data file in one optimization matrix. The matrix includes the goals, i.e. economic, production-oriented and environmental ones, and the constraints that the dairy farming system has to meet. The optimization matrix is described in Chapter 5.

In the first iteration all goals are optimized without any restrictions on the other

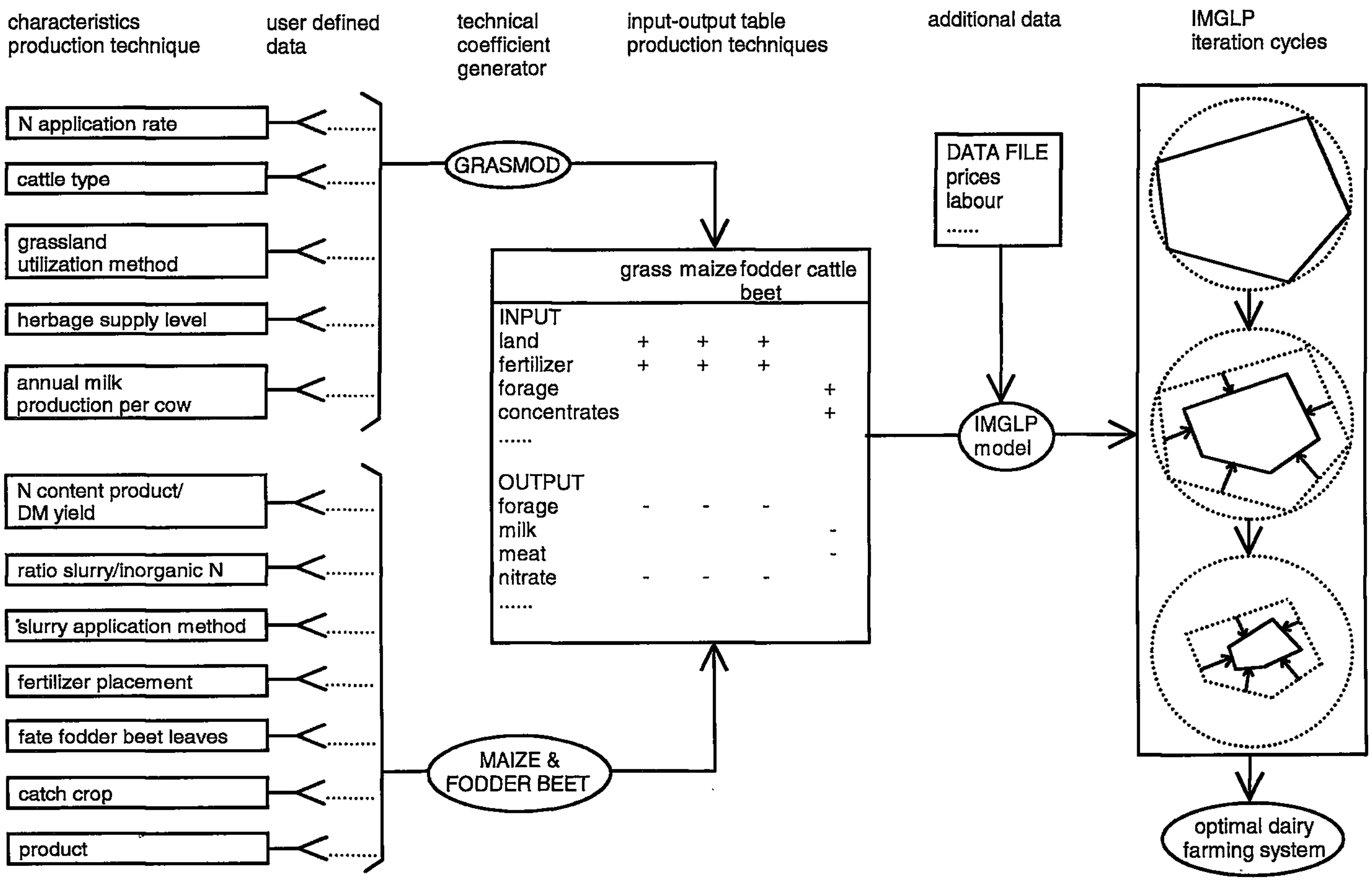

Figure 1.2 Schematic presentation of the Dairy Farming Model used for optimization of dairy farming systems.

goals and the maximum area representing feasible solutions is established (Figure 1.2, area bordered by solid lines in the upper circle). In the following iterations, the least favourable values of the goals are improved and the feasible area is reduced (Figure 1.2, middle circle). Finally, after the last iteration cycle, the accepted area is established, i.e. that part of the solution space in which all goals have values acceptable to all interested parties (Figure 1.2, bottom circle). All dairy farming systems that meet the constraints as set by the boundaries of the accepted area are considered optimal systems. However, by emphasizing different goals during the course of the optimization procedure, different sets of production techniques are likely to be selected. Hence, different users end up in different corners of the accepted area. This optimization procedure is described at regional level for dairy farming on well-drained sandy soils in the Netherlands in Chapter 6 and for the situation on the experimental dairy farm 'De Marke' in Chapter 7.
The Dairy Farming Model can be used to support policy development. By quantifying the trade-offs between the various goals, the scope for policy measures is made explicit. This information can be used as a guide to agricultural development as propagated by policy makers, the extension service and farmers. During the process of quantification of technical coefficients gaps in knowledge become visible. This information may serve as a guide for setting priorities to research.

2. GRASMOD, a grassland management model

To quantify inputs and outputs for a wide range of grass production and utilization techniques in a consistent manner, the technical coefficient generator GRASMOD was developed. The model can also be used independently to examine the effects of nitrogen application and grassland management on grass and milk production and on nitrogen emissions to the environment.

2.1. Outline of the model

The model provides a framework for the quantification of nitrogen (N) flows and herbage production in grassland for dairy farming. Phosphorus (P) flows are also quantified, but in less detail. All inputs and outputs are quantified for one hectare of grassland during the growing season, lasting from 1 April to 1 November. The winter period is taken into account in the IMGLP model (Chapter 5).

Grass production and utilization techniques are characterized by fertilizer application rate and grassland utilization method. Growing conditions that cannot be influenced by management and nitrogen supply are standardized. GRASMOD applies to a well-drained sandy soil with a favourable soil structure under average weather conditions. So far, the influence of water availability has not been taken into account in GRASMOD. It has been assumed that all operations required for good grassland management are carried out, so that a good quality sward is achieved. The labour and capital required for these operations are taken into account in the IMGLP model (Chapter 5). The equations and assumptions used in GRASMOD have been derived from the literature, standards used by the Dutch extension service and in consultation with experts. This study focuses on quantification of attainable yield levels (Rabbinge, 1993).

GRASMOD is an annual N mass balance model, which integrates existing information on N fluxes in a consistent manner. It examines inputs and outputs from the system and considers internal N pools and sinks (soil, herbage, animals) connected by N fluxes (accumulation/depletion, uptake by plants, intake by animals). Separate N balances are drawn up for the organic and inorganic N pools in the soil, for grassland and animals. A disadvantage of mass balance models is that they are not mechanistic and hence, not explanatory. However, insufficient data are available to permit a full understanding of the quantitative aspects of N cycling in grassland and mechanistic models cannot be properly validated. In that situation, mass balance models can provide a partial understanding.

Table 2.1 Definitions of the indices of grass production and utilization techniques and numerical values used in this study.

N	N application rate (kg ha^{-1} yr^{-1})
1	100
2	150
3	200
4	250
5	300
6	350
7	400
8	450
B	Grassland utilization method
1	zero grazing, no maize supplementation
2	zero grazing, supplementation with whole plant maize silage
3	day-and-night grazing, no maize supplementation
4	day grazing, supplementation with whole plant maize silage
Y	Cattle type
1	dairy cow (> 2 years)
2	calf (0-1 year)
3	yearling (1-2 years)
M	Milk production level (kg cow^{-1} yr^{-1})
1	5 000
2	6 500
3	8 000
C	Herbage supply level (proportion of the maximum herbage supply)
1	1.0
2	0.9
3	0.8
F	Product of conservation and dry matter yield at cutting (kg ha^{-1})
1	hay, 4 000
2	grass silage, 4 000
3	grass silage, 3 000
4	artificially dried grass, 3 000

They indicate trends, expose knowledge gaps and suggest the relative importance of a particular N cycle process (Hauck & Tanji, 1982). Scholefield et al. (1991) developed a mass balance model for one grassland utilization method, which can be applied to various physical environments. GRASMOD has the advantage that various grassland utilization methods can be selected, making it applicable to a wide range of milk production systems. However, it is not yet possible to vary the physical environment.

2.1.1. Characteristics of grass production and utilization techniques

Grass production and utilization techniques are characterized by N application rate (N), grassland utilization method (B), cattle type (Y), milk production level (M), herbage supply level (C) and product of conservation (F). The definitions and numerical values of these indices are given in Table 2.1.

The N application rate can be fixed at any value. In this study the minimum was set at 100 kg ha^{-1} yr^{-1}, increasing in steps of 50 kg to a maximum of 450 kg ha^{-1} yr^{-1}. In GRASMOD, only inorganic fertilizers were considered, which can be replaced by slurry in the IMGLP model.

In accordance with current practice (Asijee, 1993), under zero grazing herbage is cut at 2 300 kg of harvestable dry matter per ha, and is fed indoors. The feed ration consists either of herbage only or of herbage combined with whole plant maize silage, from now on referred to as maize silage. Day-and-night grazing and day grazing are both rotational grazing systems. In the former, cattle is outside day and night and herbage is the main component of the feed ration. In the latter, cattle is outside during the day and inside at night and its feed is supplemented with maize silage. In both systems the animals are shifted every four days to another field with a harvestable dry matter yield of 1 700 kg ha^{-1} (Asijee, 1993).

Young stock is kept either under zero grazing without maize supplementation or under a day-and-night grazing regime. Under the latter regime, calves are outdoors for only four months (end of May - 1 October), while yearlings are outside throughout the whole grazing season.

To evaluate the influence of milk production level per cow on the N efficiency of the systems, three production levels have been defined: 5 000, 6 500 and 8 000 kg milk cow^{-1} yr^{-1}. In the Netherlands, average production per cow in 1992 was about 6 500 kg fat and protein corrected milk cow^{-1} (Agricultural Economics Research Institute & Netherlands Central Bureau for Statistics, 1995).

At a herbage supply level of 1.0, the diet contains the maximum amount of herbage, given energy requirements and maximum herbage intake. Hence, concentrates are only fed if necessary to provide an adequate energy supply. At a

herbage supply level of 0.9 and 0.8, concentrates replace 10 and 20 % of the herbage, respectively. This applies to dairy cows only.
If herbage is conserved, it is either harvested at a dry matter yield of 3 000 or 4 000 kg ha^{-1}. At 3 000 kg ha^{-1}, grass is ensiled or artificially dried. At 4 000 kg ha^{-1} it is ensiled or made into hay. Hay and silage are only fed during the winter period. Artificially dried grass could be fed in summer as a concentrate. However, during that period the diet contains so much protein that artificially dried grass is not recommended. Hence, the production of conserved grass is a component of GRASMOD, but consumption is treated in the IMGLP model. The amount of herbage conserved can be set by quantifying a cutting percentage.

2.1.2. Structure of the model

The structure of the model is based on N flows through the dairy farming system, as shown in the diagram in Figure 2.1. The numbers in brackets in the text refer to the corresponding numbers in Figure 2.1.
Inorganic N in the soil originates from mineralization (1), atmospheric deposition (2), fertilizers (3) and urine (20). Nitrogen is taken up by the sward from the inorganic N pool (4). Herbage is consumed by cattle and part of the production is

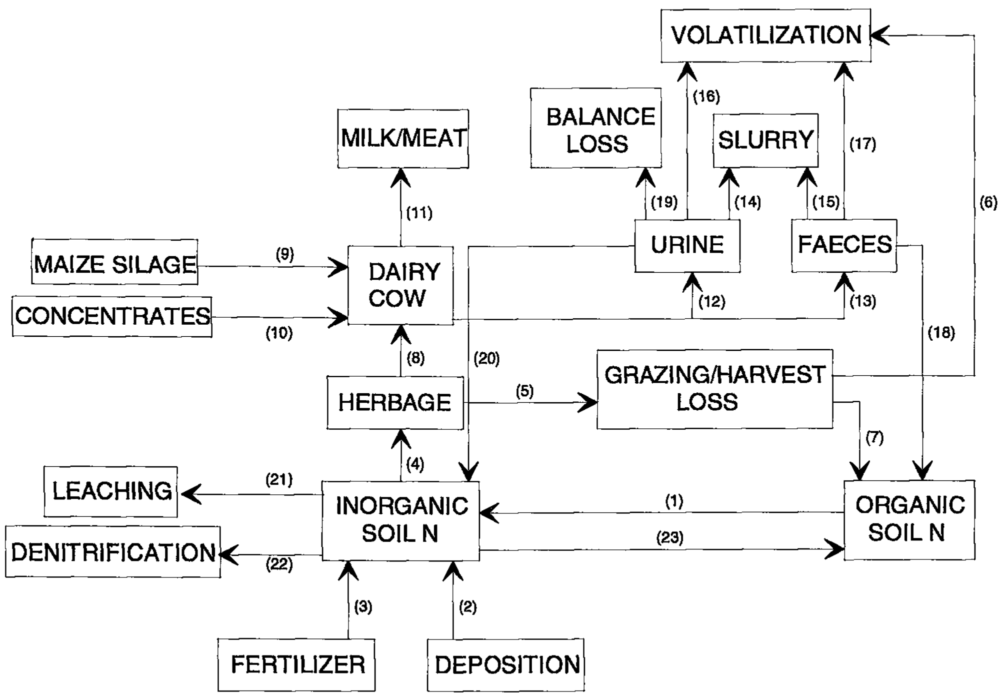

Figure 2.1 Diagram of N flows in dairy farming systems.

lost as grazing or harvest losses in the field (5). Part of the N in grazing and harvest losses volatilizes as ammonia (6) and part contributes to the soil organic N pool (7).
Stocking rate is calculated from net herbage production and energy requirements per animal, taking into account maximum dry matter uptake from forage. The ration consists of grass (8), supplemented with maize silage (9) and concentrates (10), if necessary.
Part of the N taken up by the animals leaves the system in milk and meat (11) and the remainder is excreted in urine (12) and faeces (13). In all grassland utilization methods for dairy cows, at least part of the N excreted is collected as slurry during milking in the stable (14, 15). During grazing, part of the N in urine and faeces volatilizes as ammonia (16, 17). The remainder of the N in faeces is organic N and contributes to the soil organic N pool (18). The remainder of the urinary N is partly lost through an unknown process, possibly chemo-denitrification (19) and partly contributes to the soil inorganic N pool (20).
Inorganic N in the soil is subject to leaching (21) and denitrification (22). It is assumed that all inorganic N not taken up by the herbage, nor denitrified or leached, is immobilized (23). In an equilibrium situation, replenishment of soil organic N by immobilization, harvest losses and faeces, equals the amount of N supplied to the inorganic N pool by mineralization (1). If this replenishment exceeds mineralization, assuming that no other losses occur than described here, N accumulates in soil organic matter. If replenishment is not sufficient to compensate for mineralization, the soil organic N pool is depleted.

2.2. Quantification of main model relationships

The emphasis in the model is on N flows in herbage production and utilization systems. The main model relationships relating to this aspect were quantified by analysing results from field experiments, experts and the literature.
In GRASMOD the relationship between N supply and herbage production is required for harvesting at 1 700, 2 300, 3 000 and 4 000 kg dry matter ha^{-1}. However, in most field experiments a constant cutting interval is used, resulting in decreasing weights of consecutive cuts due to decreasing growth rates over the course of the growing season. An extensive field experiment (PAW 970) with harvesting at predetermined herbage yields, was carried out by Van Steenbergen in the period 1964-1973 (Van Steenbergen, 1977). This experimental set up ruled out the interaction between N application rate and cutting frequency. The experiment was established at 24 permanent grassland sites, representing eight major combinations of soil type and soil moisture regime in the Netherlands. Three different locations were selected for each combination of soil type and soil

moisture regime and these were considered replicates. Botanical composition indicated good soil fertility and good grassland management. Each replicate consisted of six plots with N application rates of 0, 100, 200, 300, 400 and 500 kg ha^{-1} yr^{-1}. The field was divided into five parts and the experiment rotated among the parts. This was done because continuous cutting, as occurred in the field experiment PAW 970, could have an influence on sward quality. Target cut weight was 4 t ha^{-1} for the first cut and 2 t for the following cuts all through the growing season. At N application rates exceeding 200 kg, the target weight of the fourth cut was about 3 t. This cutting regime imitates grazing with one or two cuts for conservation. For a detailed description of the lay-out of PAW 970, see De Boer (1966), Van Steenbergen (1977) and Van der Meer (1982). The results from the freely draining sandy soils with an average water supplying capacity of 160 mm have been used for this study.

2.2.1. N supply and herbage yield

The response of herbage yield to N application is the result of the combined effects of N application on N uptake by the crop and of N uptake on dry matter yield. The data from PAW 970 are represented as a three quadrant diagram, as introduced by de Wit (1953; Figure 2.2). This representation facilitates analysis of field experiments with respect to the relationship N uptake - herbage yield, N supply from other sources than fertilizer, mainly by the soil and deposition, and the apparent N recovery of fertilizer (Van der Meer & van Uum-van Lohuyzen, 1986).

Figure 2.2 shows that at a similar cutting frequency, the relationship between N uptake and herbage dry matter yield is identical for the three sites.

Cutting frequency strongly affects this relationship. After harvesting, the herbage growth rate is reduced over a certain period of time, due to defoliation. The drastic reduction in leaf area results in reduced light interception and thus reduced photosynthesis. It takes some time before the growth rate is restored.

Cutting frequency determines the number of periods with reduced growth and hence the total annual length of that period. Therefore, total annual dry matter production decreases with increasing cutting frequency (Holliday & Wilman, 1965; Sibma & Alberda, 1980; Prins, 1983; Sibma & Ennik, 1988).

Annual N uptake by herbage is mainly governed by the N application rate and far less by the cutting frequency (Holliday & Wilman, 1965; Cowling, 1966; Alberda, 1973; Wieringa, 1978; Sibma & Alberda, 1980; Prins, 1983; Sibma & Ennik, 1988).

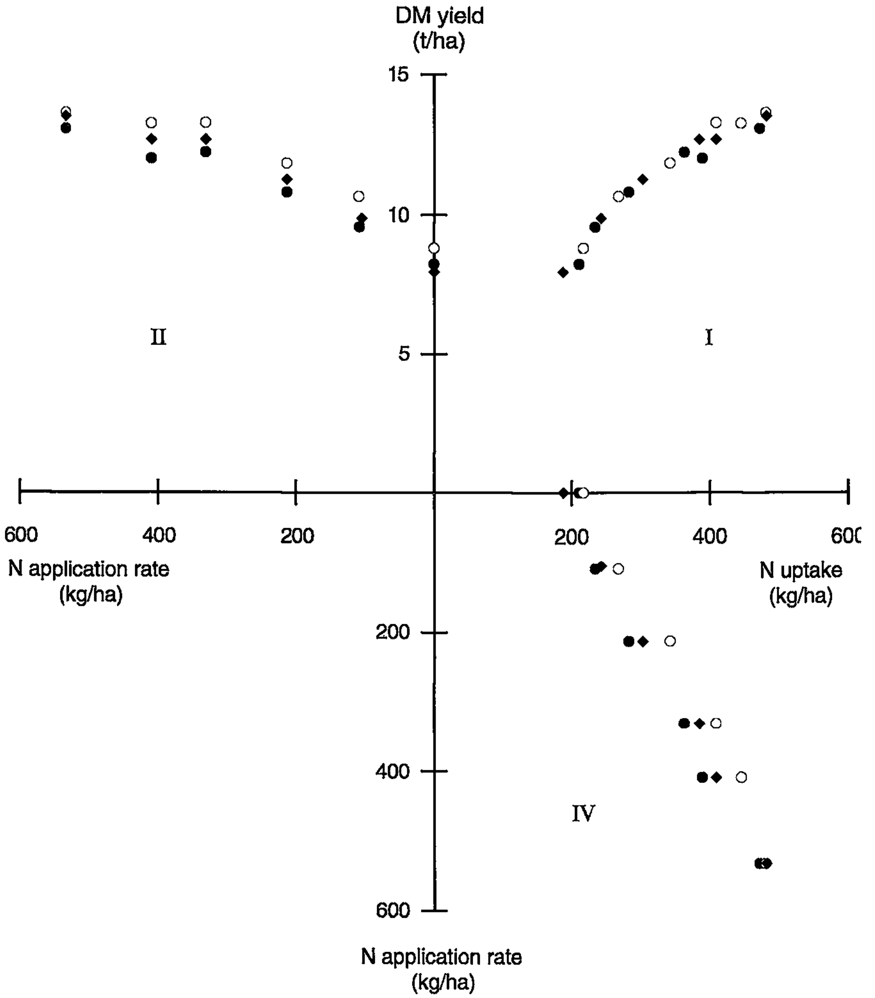

Figure 2.2 Average effect of N application rate on N uptake (quadrant IV) and herbage yield (quadrant II) for freely draining sandy soils with a good waterholding capacity at three sites in the field experiment PAW 970; ● site 1; o site 2; ◆ site 3.

Hence, N uptake in GRASMOD is assumed to be determined by the N application rate only, irrespective of the cutting frequency.

The data in Figure 2.2 were re-analysed to develop standardized production curves at four harvesting frequencies. It was assumed that after harvesting, initial regrowth is exponential, followed by linear growth after full ground cover has been achieved (Alberda, 1968). Finally, the growth rate slowly decreases, but herbage is usually harvested before this last phase is reached. The initial biomass

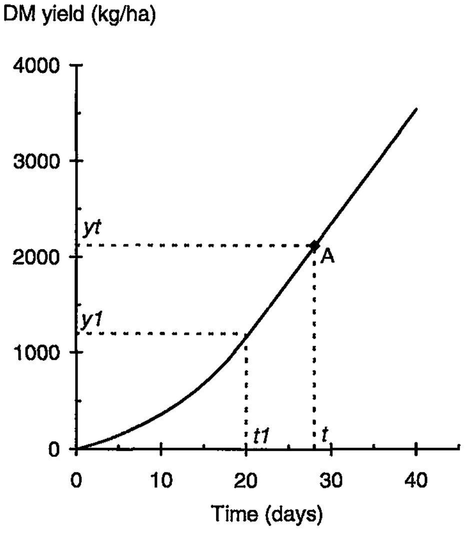

Figure 2.3 Regrowth of herbage after harvest. Y_1: yield at full ground cover; t_1 days after cutting required to reach Y_1; Y_t: herbage yield at cutting; t: days required to reach Y_t; A: data point in PAW 970.

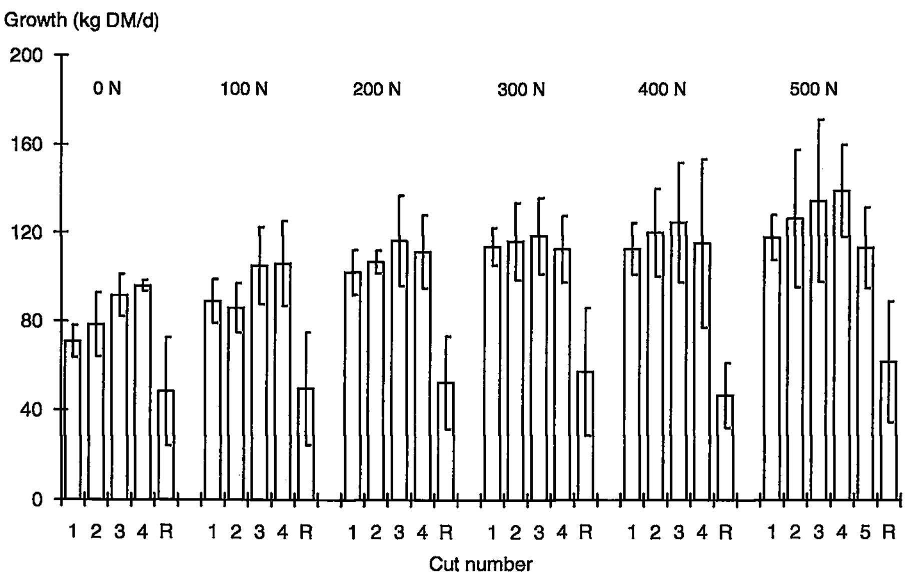

Figure 2.4 Average growth rates in the linear growth phase and the standard deviation (kg ha^{-1} d^{-1}), for all cuts and N application rates at one site in PAW 970.

after harvest that contributes to photosynthesis (Y_0) and herbage yield at full ground cover (Y_1) were estimated at 300 and 1 200 kg dry matter ha^{-1}, respectively (Alberda & Sibma, 1968; Alberda, 1973; Lantinga, 1985; Sibma & Ennik, 1988; Spitters et al., 1989). Hence, total leaf biomass at full ground cover, which is generally reached at a leaf area index of about 4, is set to 1 500 kg dry matter ha^{-1}. This results in a specific leaf weight of 275 cm^2 g^{-1}: a reasonable value for grass (Lantinga, 1985).

For each cut in PAW 970, dry matter yield (Y_t) and the number of growing days (t) were known. On the assumption that growth rate does not change abruptly, the moment at which full ground cover was achieved (t_1) and the relative and the linear growth rates (RGR, LGR) were calculated, based on the following equations:

$$Y_t = Y_0 * e^{RGR*t} - Y_0 \qquad \text{for } Y_t < Y_1$$

$$Y_1 = Y_0 * e^{RGR*t_1} - Y_0$$

$$Y_t = LGR * (t-t_1) + Y_1 \qquad \text{for } Y_t > Y_1$$

with:

Yt	:	herbage grown in t days (kg ha^{-1})
t	:	number of growing days (d)
Y_0	:	initial biomass that contributes to photosynthesis (kg ha^{-1})
Y_1	:	herbage yield at which full ground cover is achieved (kg ha^{-1})
t_1	:	number of days required to achieve full ground cover (d)
RGR	:	relative growth rate (kg kg^{-1} d^{-1})
LGR	:	linear growth rate (kg d^{-1})

Figure 2.3 shows herbage growth according to these equations as a graph.

In Figure 2.4 average growth rates and standard deviations during the linear phase of regrowth over ten years are given for all cuts and N application rates at one site. The results for the two other sites are comparable. As the treatments were identical for all years, the variation in growth rates is the result of differences in weather conditions during the ten years of the experiment.

In the original analysis, onset of growth was fixed at 1 April for all years (Van Steenbergen, 1977). This is rather early, which may have resulted in an underestimation of the growth rate of the first cut. However, the effect on total yield is small. For the calculations in GRASMOD 1 April was also taken as the start of the growing season. The influence of weather conditions on growth rate in spring was small (Figure 2.4).

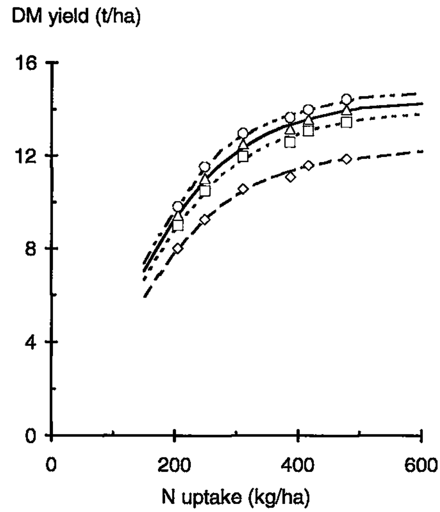

Figure 2.5 The relationship between N uptake and herbage yield at four harvesting frequencies: 1 700 (-----), 2 300 (·····), 3 000 (——) and 4 000 (– ·· – ··) kg ha^{-1}.

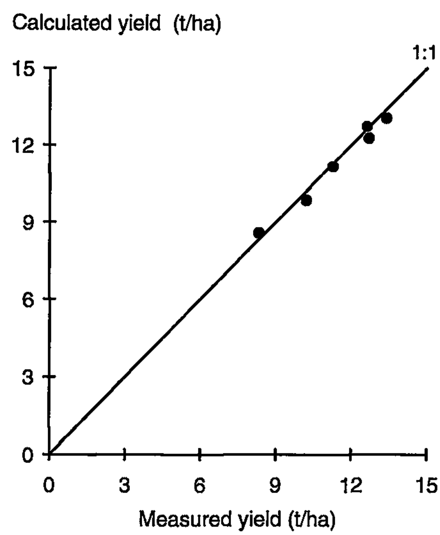

Figure 2.6 Comparison of herbage yield as measured in PAW 970 and as calculated with GRASMOD.

In late summer and autumn, growth rates are lower due to lower radiation and temperatures. Therefore, the cuts in which the herbage had grown largely after 15 August were lumped together (R in Figure 2.4). Water availability in this period depends partly on rainfall and weather conditions in summer. After a dry summer all available water has been used up and drought stress may occur. Thus, fluctuating weather conditions in summer partly explain the wide variation in growth rate during the final period.

Figure 2.4 shows that at low N application rates the standard deviation is smaller than at high rates. This suggests that at higher N availability, water supply had a greater effect on growth rate. Thus, water availability limited herbage production in some years.

Figure 2.4 also shows that during summer, average growth rates at a given N rate did not vary much among cuts and therefore, the growing season was divided into three periods: 1 April to harvest of the first cut, from harvest of the first cut to 15 August and from 15 August to 1 November. For each of the three periods the number of days required to reach a closed canopy and the linear growth rates were averaged. Subsequently, the number of days required for the production of 1 700, 2 300, 3 000 and 4 000 kg ha^{-1} were calculated, and finally the annual herbage yield was derived from the number of cuts that could be harvested.

Average N uptake at each fertilizer level, as derived from PAW 970 (Figure 2.2), was applied to all four cutting frequencies, assuming that harvesting frequency did not influence N uptake. The resulting relationships are presented in Figure 2.5. The symbols represent the calculated herbage yield at the average measured N uptake. The lines have been eye-fitted.

Using these relationships, the model was run for the harvesting regime applied in PAW 970, to check the calculations. Figure 2.6 shows that the results from GRASMOD are close to the original dataset.

2.2.2. Nitrogen supply and nitrogen uptake

In non-fertilized grassland, inorganic N in the soil originates from the decomposition of organic matter and atmospheric deposition. On sandy soils in the Netherlands N uptake by grass in such situations generally varies between 100 and 250 kg ha^{-1} yr^{-1}, depending on soil conditions, age of the sward and prior grassland management, the average being about 150 kg ha^{-1} yr^{-1} (Van der Meer & Van Uum-van Lohuyzen, 1986).

Figure 2.2 shows the relationship between N application rate and N uptake for three sites on freely drained sandy soils in PAW 970. Average N uptake in the

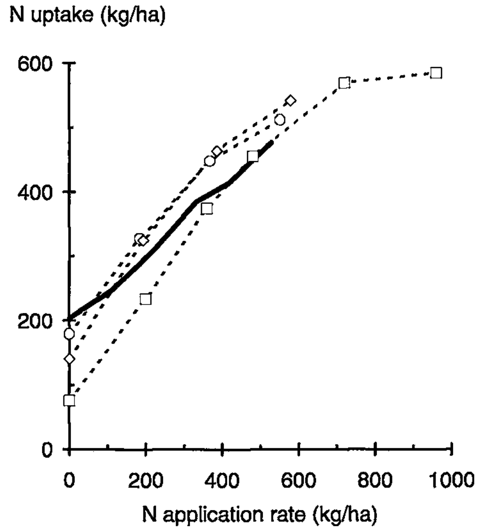

Figure 2.7 The relationship between N application rate and N uptake for experiments in Den Ham (1979-1983 --o--), Ruurlo (1980-1984 --◊--), Finsterwolde (1974-1979 --□--) and PAW 970 (1964-1973 ——).

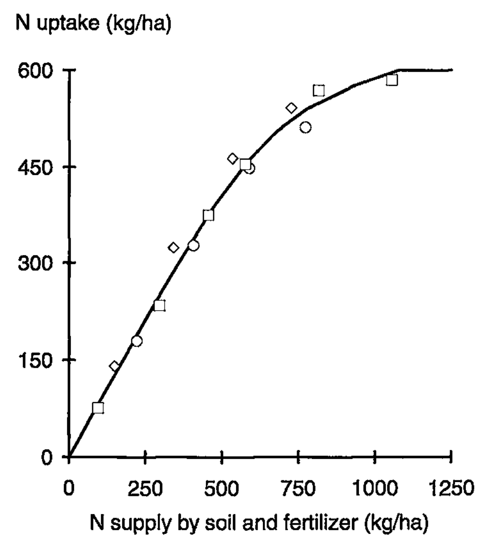

Figure 2.8 The relationship between the amount of N supplied by natural sources and fertilizers and N uptake for Den Ham (1979-1983 o), Ruurlo (1980-1984 ◊), Finsterwolde (1974-1979 □) and according to GRASMOD (——).

non-fertilized situation was 204 kg ha^{-1} yr^{-1} (Van Steenbergen, 1977). Apparent N recovery, defined as the proportion of applied fertilizer N taken up by the herbage, was rather low, i.e. 40-50 %.
There are several reasons for such a low recovery. It may have been due to the presence of clover in the swards (Reid, 1970). At increasing fertilizer rates, the competitive ability of grass increases, and clover content, and thus N fixation decreases. Hence, N fixed by clover is gradually substituted by fertilizer N (Van der Meer, 1982). An extensive analysis of the results from N fertilizer experiments on grassland in the Netherlands indicated that N recovery has increased between 1970 and 1985 from about 50 to 80% (Van der Meer & Van Uum-van Lohuyzen, 1986). This may be the result of a reduction in the C/N ratio of soil organic matter as a result of more intensified pasture production and utilization, leading to a decrease in net immobilization of applied N.
In conclusion, the apparent N recovery, as established in PAW 970 seemed too low for current grass production and utilization techniques. Therefore, the results of other experiments on sandy soils with a maximum production level comparable to that of PAW 970 were used to quantify apparent N recovery. Figure 2.7 shows the relationship between N application rate and N uptake by grass in three such experiments (Snijders et al., 1987; Prins, 1983). N uptake in the non-fertilized situation varied between sites and influenced the position of the lines. To take this effect into account, N uptake was expressed in relation to the total N supply, from both natural sources and fertilizers. It has been assumed that the efficiency of N uptake from natural sources equals that from the lowest fertilizer rate in each experiment, as the recovery appears fairly constant at low N application rates. N available from natural sources, thus calculated, was added to the fertilizer rate, and N uptake was again related to the total N supply (Figure 2.8).
The average initial slope of the curve is 0.85 kg N uptake per kg N supplied. Assuming the amount of N taken up without fertilizer application was 150 kg ha^{-1}, the amount of N available in the soil, originating from atmospheric deposition and mineralization of organic N was 176 kg ha^{-1}. It has been assumed that deposition is distributed evenly over the whole year and that on average it is 45 kg N ha^{-1}. N deposited in late autumn and winter is subject to losses. It has been estimated that 70 % of the annual N deposition is available for plant uptake (Middelkoop & Aarts, 1991, Van der Meer, pers. comm.), i.e. 31 kg ha^{-1}. Hence, 145 kg N ha^{-1} originates from the mineralization of organic N.
Grass is a perennial crop with a long growing season compared to annual crops. However, part of the decomposition of organic matter occurs outside the growing season, as the minimum temperature required for herbage growth is

Table 2.2 Summary of assumptions with respect to soil N for the non-fertilized situation.

	Atmospheric deposition	Mineralization soil organic N	Total
Total inorganic N soil (kg ha^{-1} yr^{-1})	45	153	198
Available for uptake (kg kg^{-1})	0.70	0.95	
N supply to vegetation (kg ha^{-1} yr^{-1})	31	145	176
N recovery (kg kg^{-1})			0.85
N yield herbage (kg ha^{-1} yr^{-1})			150

somewhat higher than that for mineralization (Janssen & Verveda, 1988). N available from mineralization in early spring is probably not lost, but can be taken up as soon as growth starts. However, N becoming available in late autumn (November), is subject to loss processes during the following winter period. On average, 95 % of the annually available N is estimated to be available for uptake by herbage, as the mineralization rate is relatively low in late autumn (Janssen, & Verveda, 1988). This implies an annual mineralization rate of 153 kg ha^{-1}. It is assumed that N fixed in roots and stubble equals the amount becoming available at decomposition and hence, does not influence the assumptions in Table 2.2. However, mineralization actually measured in the field includes N from decaying biomass. Hassink et al. (1994) estimated the amount of organic N added to the soil with dead root and crop residues at 245 kg ha^{-1}, of which about 170 kg becomes available during the first year.

Table 2.2 summarizes the assumptions with respect to soil N. These assumptions are rather ambiguous due to lack of information. However, they are required to quantify the N balance of the soil and of grass production and utilization techniques.

2.2.3. Herbage quality

The nutritive value of the herbage is expressed both as energy and protein values. For dairy cattle, the net energy value of feeds is expressed as net energy for lactation (NEL) in kJ kg^{-1} DM. NEL value of herbage is calculated from the metabolic energy (ME) and the gross energy (GE) content of the forage. The gross energy content hardly varies and is fixed at 18 410 kJ kg^{-1} DM.

The metabolic energy content depends on digestible organic matter (DOM) and digestible crude protein (DCP) content (Van Es, 1978):

$$NEL = 0.6 * (1 + 0.004 * (100 * ME/GE - 57)) * 0.9725 * ME \quad kJ\ kg^{-1}$$

$$ME = 14.23 * DOM + 5.86 * DCP \quad kJ\ kg^{-1}$$

Digestible organic matter content (DOM) is calculated from crude fibre content (CF), crude ash content (CASH), the number of days between harvest and 1 April (d) and, if grass is ensiled, DM content (DM), using an empirical regression equation (Corporaal & Steg, 1990). For wilted silage the equation is:

$$DOM = 1027 - 0.77 * CF - 1.23 * CASH - 0.03 * DM - 0.3*d \qquad g\ kg^{-1}$$

For other products the form of the equation is similar, but different parameter values are used.

The energy value of the herbage in PAW 970 was established only occasionally. To calculate the energy value, crude fibre and crude ash content had to be estimated. Crude ash content varies with N content of the herbage and with harvest frequency. Crude fibre content increases with the age of the herbage, but is hardly influenced by N application rate (Van Vuuren et al., 1991). Based on data sets from the Central Bureau for Animal Feeds (1993) and Vellinga (pers. comm.) the crude fibre and crude ash contents were estimated as indicated in Table 2.3.

Digestible crude protein is calculated from the N concentration (N) and crude ash content in herbage as calculated for PAW 970, using a regression equation developed by the Central Bureau for Animal Feeds (1993). For fresh grass the equation is:

$$DCP = 0.959 * 6.25 * N + 0.04 * CASH - 40 \qquad g\ kg^{-1}$$

For other products the form of the equation is similar, but parameter values differ. In GRASMOD the grazing season is split in two periods with regard to milk production: before and after 15 July. The nutritive value of fresh herbage was

Table 2.3 Crude fibre and crude ash contents of herbage at various growth stages and for various products. N: N concentration of herbage in g kg^{-1}. Source: Central Bureau for Animal Feeds (1993) and Vellinga (pers. comm.).

Growth stage (kg DM ha^{-1})	Product	Crude fibre (g kg^{-1})	Crude ash (g kg^{-1})
1 700	fresh	205	1.14 * N + 59
2 300	fresh	215	0.97 * N + 63
3 000	silage	240	1.15 * N + 78
3 000	artificially dried grass	240	1.18 * N + 95
4 000	silage	260	1.15 * N + 78
4 000	hay	275	1.15 * N + 78

calculated separately for both periods (Subsection 2.2.4). For wilted silage no distinction was made for the nutritive value in the two periods, as it is assumed that herbage from both periods is mixed when fed.
The protein value is expressed in true protein digested in the small intestine (DVE) and degraded protein balance (OEB), according to the current Dutch valuation system (National Reference Centre for Agriculture, 1991; Tamminga et al., 1995). Both can be calculated from parameters similar to those used for calculation of the energy value, complemented with crude fat content, undegraded starch and end products of fermentation in ensiled feeds. Values for the latter parameters are listed in the Feeding Standard for Domestic Animals (Central Bureau for Animal Feeds, 1993).
The protein value was not calculated for the two periods separately, because the DVE value hardly varies during the growing season (Working Group for Standards in Fodder Supply, 1991).

2.2.4. Animal feeding

At a herbage supply level of 1.0, the feed ration of the dairy stock is based on grass and, depending on the grassland utilization method, maize silage. Concentrates are only used as a supplement to meet energy and protein requirements. Two types of concentrates have been defined for the summer period: a standard and a low-nitrogen concentrate with N contents of 23 and 14.7 g kg^{-1} DM, respectively. The low-nitrogen type is comparable to ground ear silage. A combination of both types was selected, to keep the DVE surplus as low as possible. Under day grazing, 4.5 kg dry matter of maize silage is fed indoors during the night covering, on average, one third of the total energy requirements. Grass silage is reserved for the winter period. By feeding maize silage, the average N content of the ration is reduced, resulting in a lower N excretion in urine and thus reduced N losses to the environment. Under day-and-night grazing no maize silage is fed. Under zero grazing, both rations, with and without silage maize, can be chosen to compare the effect of keeping cows inside year-round under both grassland utilization systems.
Dairy stock requires energy for maintenance, milk production, grazing, pregnancy and, for young cows, weight gain. The energy requirements for maintenance depend on the weight of the cow. The maintenance requirements for a cow of 600 kg are 34 630 kJ d^{-1}.
Energy requirements for milk production are calculated for cows producing 5 000, 6 500 and 8 000 kg milk per year. Milk production varies during the lactation period. Cows calving at the beginning of February produce 53.5 % of their milk during the summer (1 May - 1 November, 184 days) and 46.5 % during

the winter period (181 days). Hence, assuming a constant average milk production level during summer and winter leads to underestimation of energy requirements at the beginning of the lactation period and overestimation at the end. Therefore, the year has been divided into five periods, based on the distribution of milk production over the lactation period (Rompelberg, 1984; Figure 2.9).

Energy requirements are calculated for each period according to the model for feed supply to dairy cows, as developed by Hijink and Meijer (1987).

The dry matter intake capacity of dairy cows depends on lactation stage, milk production level and the energy content of the feed. At a higher milk production level intake capacity increases, but energy requirements increase more than proportionally. In the first period after calving (1 February - 1 May), energy requirements cannot be met, because of physiological limits on dry matter intake. The weight of the animal decreases due to mobilization of reserves and these are replaced during the summer period. Based on Hijink & Meijer (1987) and the Central Bureau for Animal Feeds (1993), it has been assumed that at milk production levels of 5 000, 6 500 and 8 000 kg cow^{-1} year^{-1} 2.5, 5.0 and 7.5 % of the energy requirements during the first period after calving have to be supplied during summer. This additional energy requirement amounts to 1 310, 3 180 and 5 620 kJ per day for cows producing 5 000, 6 500 and 8 000 kg milk per year, respectively, and is distributed proportionally over the two periods.

Feed intake in each period is also calculated according to the model for feed supply to dairy cows (Hijink and Meijer, 1987). The relationships in this model have been derived for a cow producing 6 000 kg milk per year, consuming 15 kg

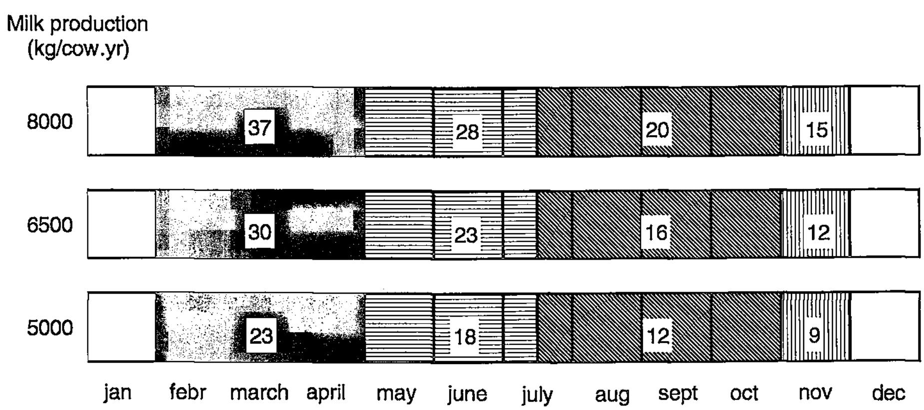

Figure 2.9 Milk production in kg cow^{-1} d^{-1} during five periods for three annual milk production levels.

of herbage dry matter per day under day and night grazing and for herbage and maize silage with a standard energy content. These relationships have been adapted to other production levels, grazing systems and feed energy contents. If the energy supply from grass and maize silage does not meet the requirements, concentrates have to be supplied. The replacement of roughage by concentrates has been calculated according to Central Bureau for Animal Feeds (1993). Total energy supply just meets requirements (Van de Ven, 1992). The protein requirement, as determined by milk production level and live weight, has been calculated according to the Central Bureau for Animal Feeds and is expressed in DVE (National Reference Centre for Agriculture, 1991; Central Bureau for Animal Feeds, 1993; Tamminga et al., 1995).

Finally, total intake of herbage, maize silage and concentrates during the whole summer period is calculated. Feed intake during the winter period is calculated in the IMGLP model and not in GRASMOD.

The ration of calves during the first three months (February-April) consists of concentrates, milk and hay. Subsequently, they shift to a grass-based diet. During their first grazing season (end of May-September) they still receive some concentrates (Pelser, 1988). Thereafter, concentrates are only supplied if energy requirements cannot be met by grass products. This also applies to the ration of yearlings.

Young stock requires energy for growth, maintenance and, for yearlings, pregnancy. The energy requirements in summer have been calculated for weekly periods according to Mandersloot (1989). These weekly values have been summed to provide a seasonal total, i.e. 3 370 MJ for calves and 8 185 MJ for yearlings, if no grazing is involved (Boons-Prins & van de Ven, 1993). In summer, young stock is raised on grass only. Hence, the DVE requirements are met anyway. Only the herbage supply level of 1.0 applies.

For more detailed information on the feed ration of cattle, see Van de Ven (1992) and Boons-Prins and Van de Ven (1993).

2.2.5. Influence of grazing on herbage production and N flows

Stocking rate is calculated from net herbage yield, i.e. gross herbage yield minus grazing losses, and the amount of herbage required per animal during summer (Subsection 2.2.4). Hence, in GRASMOD stocking rate is expressed per ha grassland used for feeding in summer. This implies that at a similar net herbage yield, stocking rate under day-and-night grazing, without maize supplementation, is lower than under day grazing with 4.5 kg maize supplementation, as more herbage per cow is required. Grass can also be cut for conservation and fed in winter. Under this grassland utilization method, the stocking rate is zero. In the IMGLP model a minimum value of 0.10 was set for the ratio of the area of grassland used for feeding in summer to the area of grassland used for conservation, as grass has to be cut at least once a year to maintain sward quality.

N load in urine and dung patches is calculated from the number and the area in the field covered by excretions and the N content per excretion. On average, dairy cows defecate and urinate 12 times a day (MacLusky, 1960; MacDiarmid & Watkin, 1972; Groenwold & Keuning, 1988). For calves and yearlings the same values have been used. It has been assumed that the excretions are spread regularly over time. Milking takes about 2 hours. Hence, under day-and-night grazing cows are outside 20 hours a day and under day grazing 10 hours. Loss of N during transfer between field and stable has been neglected. These assumptions imply that 10 urine and dung patches per cow per day are deposited in the field under day-and-night grazing and 5 under day grazing.

The area affected by dairy cows has been set at 0.68 m^2 per urination and 0.08 m^2 per defecation (MacDiarmid & Watkin, 1972; Whitehead, 1986; Groenwold & Keuning, 1988). For calves and yearlings the area of a urination has been estimated at 0.35 and 0.50 m^2 (Mandersloot, 1992) and a defecation covers 0.04 and 0.06 m^2, respectively.

Distribution of urine and dung patches over the field and the total area covered is calculated according to the Poisson distribution (Peterson et al., 1956), which accounts for overlap of patches. It has been assumed that faeces and urine are distributed at random over the field. Hence, the concentration of excreta near watering points and gates is disregarded. The area covered x times with faeces or urine (P(x)) is estimated from the expectation value μ, i.e. the area covered without overlap. The value of μ depends on the total number of excretions (d) and the surface area per excretion (area):

$$\mu = d * \text{area} \qquad (\text{ha ha}^{-1})$$

$$P(x) = e^{-\mu} * \mu^x / x! \qquad (\text{ha ha}^{-1})$$

The areas not covered and covered once and twice with urine (U0, U1, U2) and with faeces (F0, F1, F2) have been calculated. Combinations of urine and faeces are calculated by multiplying the respective areas. The grazing area is thus divided into nine parts covered less than three times with faeces or urine and a remaining part covered three times or more. The remainder is so small that for the purposes of this study a further subdivision was not required (Table 2.4).

The increased herbage production at the edge of dung patches, is offset by a decrease due to covering by faeces, which completely prevents herbage growth for some time (Middelkoop, 1989; Deenen, pers. comm.).

Table 2.4 The proportion (%) of the field parts U_iF_j and the remainder (RR) for day-and-night grazing, 250 kg N ha^{-1} yr^{-1}, no cutting for conservation, cows producing 6 500 kg milk yr^{-1} and a herbage supply level of 1.0.

Urine	Faeces			R
	F0	F1	F2	
U0	64.2	25.5	5.0	
U1	3.0	1.2	0.2	
U2	0.1	0.0	0.0	
R				0.8

For each of the nine field parts, the N load of urine and faeces is calculated in kg per ha urine/faeces patch. Covering by faeces does not lead to additional N uptake or herbage production. About 60 % of urinary N is available in inorganic form in the soil for plant uptake (Vertregt & Rutgers, 1988). Urine is excreted throughout the growing season but, assuming that inorganic N in urine is identical to fertilizer N, it has little effect on herbage growth when voided in September/October. Experimental results (Van der Meer & Van Uum-van Lohuyzen, 1989; Middelkoop, 1989; Van der Meer & Whitehead, 1990) indicate that on average, 30 % of the N voided in urine was actually taken up during the growing season, i.e. 50 % of the inorganic urinary N available for plant uptake.
Assuming that N recovery was 75 %, comparable to that at fertilizer levels of 200 - 400 kg N ha^{-1} yr^{-1}, seasonal effects reduced potential N uptake to 65 % (50 / 75 * 100 %) of the inorganic urinary N in the soil.
Considering the period in the growing season during which urine is present and the period N application is effective, leads to a similar estimate. Assuming that urine N voided in the preceding season is not carried over the winter period, no urinary N is present during the growth period of the first cut. If it is assumed, additionally, that, similar to fertilizer N, urine N is hardly effective after 15 September, then urinary N can be taken up during 65 % of the growing season (1 April - 1 November).
In GRASMOD, it has been assumed that seasonal effects reduce the proportion of urinary N potentially available for plant uptake, to 65 %. This implies a maximum seasonal N uptake of 39 % of the total N voided in urine (0.65 * 0.60). For each of the ten field parts, including the uncovered part, N uptake by herbage and herbage production are calculated separately. Next the weighted averages per ha are calculated.

The stocking rate has been adapted to net herbage production. However, N voided by grazing animals results in additional herbage production and a higher N content of the herbage, which in turn results in increased N excretion with urine. Therefore, all calculations are repeated, taking into account the effects of urinary N on herbage production and N uptake. The second iteration again results in additional herbage and a higher N uptake. Both herbage production and N uptake move towards an equilibrium. However, after the second iteration the main effects of grazing have been taken into account and more iterations have little effect. Strictly speaking, the influence of grazing should be calculated for each harvesting period separately. However, the time resolution of the model is one year and the second iteration is executed to approximate the average influence of grazing.

2.2.6. Nitrogen losses to the environment

Nitrogen not taken up by herbage nor accumulated in the soil is lost from the production system by leaching or denitrification of nitrate or volatilization of ammonia. The production system considered in GRASMOD includes the rooted zone of the soil. Therefore, N accumulating in the rooted soil zone is not considered a loss. It may become available again at a later stage and can subsequently either be taken up by plants or leached or denitrified.

There is a close correlation between fertilizer application rate and nitrate leaching losses. The most important factors that influence nitrate leaching at a particular level of N application are soil type, soil use, ground water table and weather conditions (Steenvoorden et al., 1986; Van der Meer & Meeuwissen, 1989). Leaching occurs when rainfall exceeds water loss by evapotranspiration and thus, in the Netherlands, mainly in the winter period. However, during wet periods in summer some nitrate may also be transported below the rooted zone.

From the results of field experiments, a relationship between fertilizer application rate and nitrate leaching has been derived for cut grass on well-drained sandy soils in the Netherlands (Figure 2.10).

Under anaerobic conditions and in the presence of oxidizable organic matter and nitrate, N may also be lost by denitrification, i.e. the reduction of nitrate via N_2O to N_2. The ratio N_2O/N_2 during the denitrification process is highly variable. Production of both gases leads to N losses from the production system, but only N_2O acts as a greenhouse gas and is harmful to the environment. Water has no direct effect on denitrification, but because of its effect on the oxygen status of the soil, soil moisture content has a major indirect effect (Corré & de Klein, 1990).

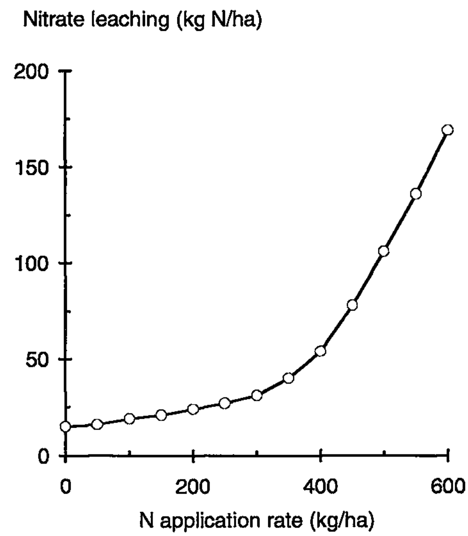

Figure 2.10 Nitrate leaching losses from cut swards on sandy soils with a deep ground-water table, as influenced by N application rate (Van der Meer & Meeuwissen, 1989).

For soils with a higher ground-water table than that presented in Figure 2.10, nitrate leaching should be corrected for denitrification. However, in GRASMOD the ground-water table has not been considered. The total amount of N lost from the soil profile, can be derived from Figure 2.10, and is not distributed between leaching and denitrification.

In the model, nitrate loss is not affected by the harvesting regime, because it does not affect N uptake by the crop and the amount of N subject to leaching. Nitrate loss in the non-fertilized situation has been estimated at 13 kg N ha^{-1} yr^{-1} (Van der Meer & Meeuwissen, 1989). This nitrate originates from the decomposition of soil organic matter and atmospheric deposition not taken up by the herbage. Nitrate loss from fertilizers can be derived from Figure 2.10. N application rates above 600 kg ha^{-1} yr^{-1} can be extrapolated form Figure 2.10, assuming that 70 % of the additional N is leached (Van der Meer & Meeuwissen, 1989). At application rates above 1000 kg N, all additional N is lost from the rooted zone.

Nitrate loss from grazed swards was calculated for each of the ten field parts separately. The N load in the various field parts after the second iteration is known and from Figure 2.10 the associated nitrate loss can be derived. Subsequently, the weighted total nitrate loss was calculated.

Ammonia volatilization originates from decaying herbage, applied slurry and, under grazing, from faeces and urine.

The grazing and harvesting losses are considered to be decaying in the field and it is assumed that 3 % of the N content volatilizes as ammonia (Vertregt & Rutgers, 1988). Slurry application is not included in GRASMOD, but in the IMGLP model, so the associated ammonia volatilization was also not included.
N application rate has an impact on ammonia volatilization from grazed swards. At increasing N application rates an increasing amount of N is excreted with urine and the proportion of urinary N that volatilizes also increases. Other factors of less importance, however, such as urine composition, cation exchange capacity of the soil and weather conditions also influence volatilization losses (Jarvis et al., 1987; Jarvis et al., 1989; Bussink, 1994). The model was developed for average weather conditions and one soil type and urine composition has not been considered. Therefore, a simple linear relationship between N application rate and ammonia volatilization, based on experimental data (Jarvis et al., 1987; Vertregt & Rutgers, 1988; Jarvis et al., 1989; Bussink, 1994), has been applied: at N application rates of 100 and 550 kg ha^{-1}, 4 and 13 % respectively of the N excreted with urine volatilizes.
Ammonia volatilization from faeces amounts to 13 % of the N excreted (Vertregt & Rutgers, 1988). Volatilization does not have to be calculated for each of the field parts separately, because, according to the assumptions described above, it is linearly related to the total N excreted in urine and faeces. Vertregt and Rutgers (1988) concluded from N balance studies with urine that after 10 days, on average 27 % of the N in urine was not accounted for, which may possibly be explained by chemo-denitrification. In the model the amount not accounted for is calculated as the difference between the amount of N voided at pasture, and the amount available for uptake plus the amount volatilized. Volatilization from inorganic fertilizers is very low and has therefore been set at zero.

2.2.7. Nitrogen balance

The consequences of combining all the processes described above, for which information has been collected from various sources, have been revealed by calculating the overall N balance of the system over the summer period, together with the N balance of animals and grassland. This is illustrated by the results obtained with GRASMOD for one situation, in which N application rate is 250 kg ha^{-1}, under day-and-night grazing, herbage supply level is 1.0, milk production per cow is 6 500 kg yr^{-1}, one cut is used for conservation as wilted silage.
The overall N balance of this dairy farming system is given in Table 2.5. It has been assumed that no other loss processes than nitrate leaching, denitrification, ammonia volatilization and the balance loss from urine patches occur.

Table 2.7 N balance of grassland in summer (kg N ha^{-1}). Definition system characteristics: Table 2.5.

	Total	Uptake herbage	Leaching + denitrification	Volatilization	Balance loss	Organic soil N	Not accounted for
Mineralization	153	124	} 13				35
Deposition	45	27					
Fertilizer	250	203	12				36
Urine	116	27	20	8	38		23
Faeces	42			5		37	
Grazing losses	59			2		57	
Total	664	379	45	15	38	94	93

Table 2.5 Overall N balance of a dairy farming system in summer (kg N ha^{-1}): N application rate is 250 kg ha^{-1}, day-and-night grazing, herbage supply level 1.0, milk production per cow 6 500 kg yr^{-1}, one cut used for conservation.

N input		N output	
Deposition	45	Milk + meat	47
Fertilizer	250	Leaching + denitrification	45
Concentrates	2	Volatilization	15
		Balance loss	38
		Slurry	32
		Silage	86
		Accumulation	34
Total	297	Total	297

Slurry produced inside during milking is not applied and wilted silage is fed in winter, so both are regarded outputs. N accumulation is calculated as inputs minus outputs.

N intake by dairy cows is 237 kg yr^{-1}, of which 47 kg is incorporated in milk and meat during summer. The N balance of the dairy cows (Table 2.6) shows that 116 kg N is voided at pasture in urine and 42 kg in faeces and that 32 kg is collected in slurry during milking.

It has been assumed that, on an annual basis, the amount of N in root and stubble biomass is in equilibrium (Neeteson et al., 1991; Subsection 2.2.4) and mineralization from these sources is not taken into account. N mineralization is 153 kg yr^{-1}, of which 124 kg is taken up (Table 2.7). N deposition is 45 kg of which 27 kg is taken up. From these two sources together 13 kg N is lost by leaching and denitrification and 35 kg is not accounted for. Out of the 250 kg N applied in fertilizer 36 kg is not accounted for. In urine 116 kg N is voided at pasture, 23 kg of which is not accounted for. All N from these sources that is not accounted for, was originally present in the soil in inorganic form. As it does not contribute to any of the loss processes, it either remains in the soil in inorganic form or it is

Table 2.6 N balance of dairy cows (kg N ha^{-1}). Definition system characteristics: Table 2.5.

	Total	Urine	Faeces	Milk + meat
Excretion	237	139	51	47
Field	158	116	42	
Stable	32	24	8	

(temporarily) immobilized. A year after application of artificial N fertilizer, often 15-40 % of the amount applied is still present in the soil due to immobilization (Whitehead & Dawson, 1984; Bristow et al., 1987; Neeteson et al., 1991). The proportion of fertilizer N not accounted for in GRASMOD is 14 %. It has been assumed that all N not accounted for is immobilized, i.e. 93 kg yr^{-1} in the system described in Tables 2.5 - 2.7.

In faeces 42 kg N is excreted on the grass sward, 5 kg of which volatilizes and 37 kg is added to the soil in organic form. Grazing losses contain 59 kg N, of which 2 kg volatilizes and 57 kg is added to the soil in organic form. Hence, in total, 94 kg N is added in organic form to the soil organic N pool. Part of the organic material added will decompose very easily, but in the model no distinction has been made between labile and stable organic matter.

Hence, in the system described, 187 kg N is added annually to the soil organic N pool. Mineralization is 153 kg N, resulting in an annual N accumulation of 34 kg. It should be noted that the N accumulation in GRASMOD has been calculated to close the N balance and is not based on measurements. However, it provides the best possible estimate at this time.

3. The influence of grassland management on production and nitrogen emissions

GRASMOD has been run for all relevant combinations of the characteristics given in Table 2.1 to quantify the inputs and outputs of the grass production techniques generated for the IMGLP model. This also demonstrates the use of the model to assess the influence of grassland management on milk production and nitrogen emission.
First, some results of GRASMOD on a per ha basis are presented and compared with the results of field experiments. All grass produced is used for feeding in summer. Cutting for conservation is not considered in this chapter. GRASMOD has been expanded to farm level (Van der Putten & Van der Meer, 1995). To be able to compare the results of GRASMOD with those obtained on commercial farms, the model was used at farm level.

3.1. Nitrogen application rate

Figure 3.1 shows the effects of the grassland utilization method and N application rate on various aspects of grass and milk production. The results are presented per ha grassland, for a herbage supply level of 1.0 and dairy cows producing 6 500 kg milk yr^{-1}. All figures apply to the summer period only.
Gross DM yield (Figure 3.1a) is largely determined by harvest frequency. At a low harvest frequency, and thus a high yield per cut, the number of regrowth periods is small, resulting in a high yield (Section 2.2). Cows start grazing at 1 700 kg DM ha^{-1} and hence, gross DM yield is low. The very small yield difference between day grazing and day-and-night grazing is due to the effect of urinary N. Under the latter system, the amount of N voided in urine on the pasture is larger than under day grazing, resulting in a higher DM yield (Table 3.1). Although the time spent outside under day grazing is only half that under day-and-night grazing, the amount of N voided in urine is not reduced proportionally due to the higher stocking rate under day grazing. The uptake of urinary N, and hence, additional DM production, decreases with increasing fertilizer application rate.
Net DM yield under day-and-night grazing is lower than under day grazing due to higher grazing losses, i.e. 20 % compared with 14 % (Figure 3.1b). The harvesting losses under zero grazing are 7 %. Hence, the difference in net yield between grazing and no grazing systems is larger than the difference in gross yield.

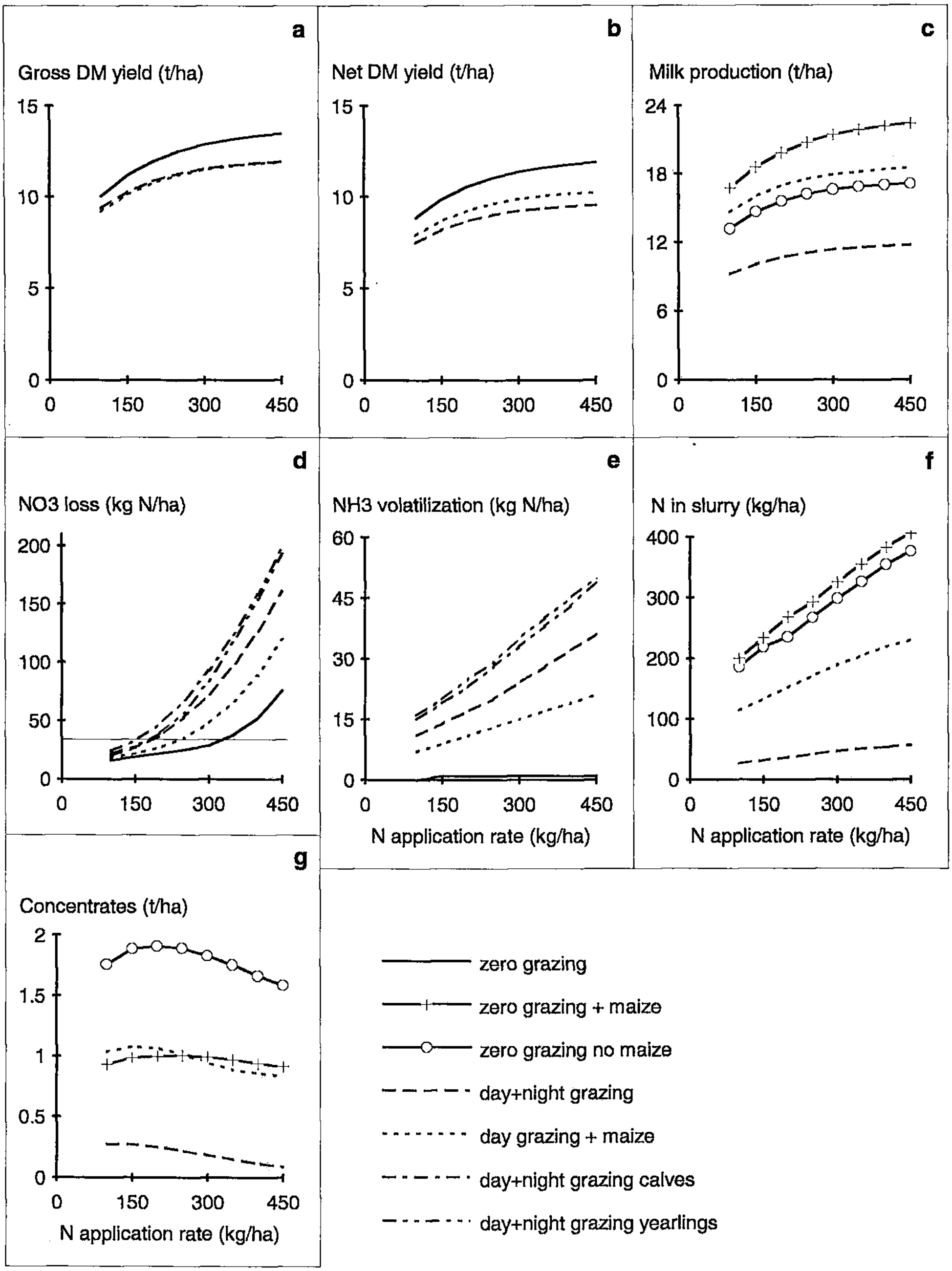

Figure 3.1 The relationship between N application rate and gross herbage yield (a), net herbage yield (b), milk production (c), nitrate loss (d), ammonia volatilization (e), amount of N collected in slurry (f) and amount of concentrates purchased (g) as calculated with GRASMOD for various grassland utilization methods.

Table 3.1 The influence of day-and-night grazing and day grazing only on the distribution of urine, extra N in the urine-affected area, dry matter yield and nitrate losses at an N application rate of 200 kg ha^{-1}, a herbage supply level of 1.0 and a milk production level of 6 500 kg cow^{-1}.

	No urine	1x urine	2x urine	>2x urine	Average
Day-and- night grazing (3.1 cows ha^{-1})					
Area affected, %	68	26	5	1	100
N in urine, kg N ha^{-1}	0	346	692	1 072	133
Yield, kg DM ha^{-1}	10 540	11 470	11 850	12 000	10 850
Nitrate loss, kg N ha^{-1}	22	48	147	287	37
Day grazing (4.9 cows ha^{-1})					
Area affected, %	74	22	4	0	100
N in urine, kg N ha^{-1}	0	224	448	690	68
Yield, kg DM ha^{-1}	10 540	11 260	11 640	11 860	10 740
Nitrate loss, kg N ha^{-1}	22	34	77	158	27

Milk production per ha grassland is greatest for zero grazing with maize supplementation (Figure 3.1c). As 4.5 kg maize cow^{-1} d^{-1} is supplied, more cows can be kept per ha grassland than without maize supplementation.

Under day grazing with maize supplementation, milk production is higher than under zero grazing without maize supplementation. The lowest milk production per ha grassland is obtained under day-and-night grazing. The grassland area required for calves and yearlings has not been taken into account.

Figure 3.1d shows nitrate losses, i.e. nitrate leaching and denitrification. Nitrate losses are lowest under zero grazing, as no animal excreta are voided at the pasture. The maximum admissible nitrate loss, based on the EU norm for drinking water, is 37 kg N ha^{-1} (Chapter 1), if denitrification is 10 %, as assumed for the sandy soil used in this study. For zero grazing this implies a maximum N application rate of 325 kg ha^{-1}. All herbage is cut and fed indoors, so nitrate losses are not influenced by the supplementation of maize. Under grazing, nitrate losses are higher due to the voiding of urine. The effect of urine on nitrate losses is much greater than on N uptake and DM yield (Table 3.1). Nitrate losses increase dramatically, especially at high N application rates (Figure 3.1d). Under day grazing less urine is voided than under day-and-night grazing, resulting in lower nitrate losses. The maximum permitted N application rate according to the EU norm is 250 kg ha^{-1} for day grazing by dairy cows and

190 kg ha^{-1} for day-and-night grazing. Calves and yearlings only incorporate N in growth. Hence, a larger proportion of the N in the ration of young stock is excreted in urine and faeces. The maximum N application rates according to the EU norm are 150 and 180 kg ha^{-1} for day-and-night grazing by yearlings and calves, respectively.

Ammonia volatilization from grassland (Figure 3.1e) is greatest under day-and-night grazing by calves and yearlings due to the high level of N excretion in urine and faeces. It increases more than proportionally with increasing N application rate (Subsection 2.2.5). Day-and-night grazing by dairy cows results in a lower, but still considerable degree of ammonia volatilization. Zero grazing leads to hardly any volatilization and day grazing to an intermediate volatilization rate.

Figure 3.1f shows that under zero grazing with maize supplementation the amount of N collected in slurry greatest. Apparently, the stocking rate in this system is so high that it offsets the influence of a low N content in maize. Under day-and-night grazing only a small part of the N excreted is collected indoors. All urine and faeces produced by calves and yearlings are voided at the pasture, as they do not go inside for milking. Part of the N in slurry volatilizes from storage and during application. This volatilization has been added to that from grassland to get an overall picture. However, this is treated in the IMGLP model.

The amount of concentrates purchased per ha (Figure 3.1g) is affected by two opposing effects. At an increasing N application rate, herbage production and hence, stocking rate increases. At a constant DM intake capacity for forage, the amount of concentrates required increases linearly with the stocking rate. However, at a higher N application rates the quality of the herbage increases and less concentrates per cow are required. Under zero grazing, the increase in stocking rate outweighs the decrease in concentrate requirements per cow at low N application rates. Above 200 kg N ha^{-1} the reverse is true. Under day-and-night grazing, the increase in stocking rate over the whole range of N applications is outweighed by the decreasing amount of concentrates per cow. Day grazing and zero grazing supplemented with maize take an intermediate position.

The amount of concentrates required under zero grazing without maize supplementation is about twice that under zero grazing with maize supplementation, although milk production per ha grassland is lower. This is due to the replacement rate of grass by maize being less than 1. Hence, roughage dry matter intake can be somewhat higher with maize supplementation and less concentrates are required. This is illustrated in Table 3.2. Total energy intake is the same for both rations.

Table 3.2 Average daily ration for dairy cows in summer under zero grazing with and without maize supplementation in kg cow^{-1} d^{-1}. Herbage supply level: 1.0; N application: 250 kg ha^{-1}; milk production per cow: 6 500 kg yr^{-1}.

Feed	Zero grazing no maize	Zero grazing with maize
Grass	12.9	10.0
Maize silage	0.0	4.5
Concentrates	2.2	0.9
Total DM intake	15.1	15.5

Assuming no other loss processes than described in Chapter 2 occur, N not lost as nitrate or ammonia, accumulates in the soil. In GRASMOD, mineralization is set at 153 kg ha^{-1} yr^{-1}. Hence, an annual input of 153 kg N to the soil organic pool is required to prevent depletion (Subsection 2.2.2). Net annual N accumulation under the various grassland utilization methods is given in Figure 3.2a.

Under zero grazing, the organic N pool is depleted over the whole range of N application rates, although depletion decreases with increasing fertilizer application rate. It should be noted that slurry is not applied, but is an output of GRASMOD. Its application is covered in the IMGLP model. Under day grazing the organic N pool is in equilibrium at an N application rate of about 180 kg ha-1. Under day-and-night grazing N accumulates in soil organic matter, the amount depending on N application rate. If the soil N pool is not in equilibrium, eventually, N mineralization will change due to either accumulation or depletion of soil N. Hence, GRASMOD has to be re-run at a higher or lower

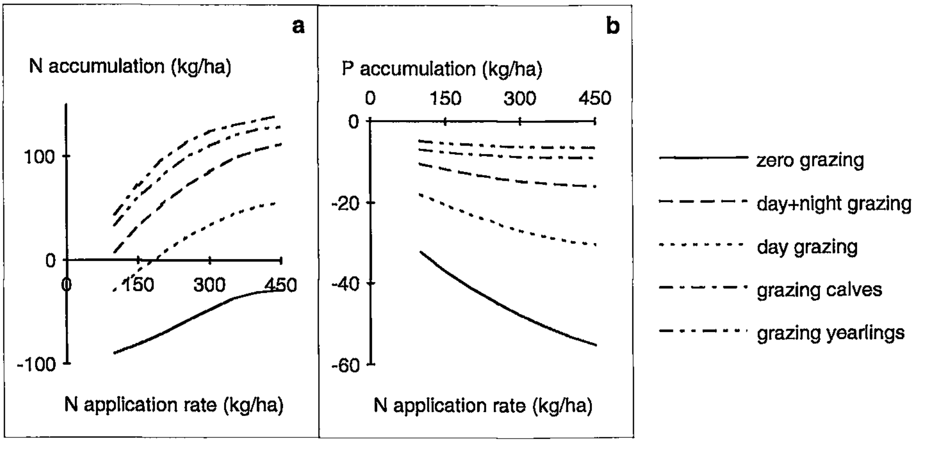

Figure 3.2 The relation between N application rate and net N (a) and P (b) accumulation as calculated with GRASMOD for various grassland utilization methods.

mineralization rate to assess equilibrium values for various combinations of grassland utilization methods and N application rates. In that case, slurry application should also be taken into account. This would require the transfer of slurry application from the IMGLP model to GRASMOD. However, changes in soil organic N are so small in relation to the total organic N pool of about 11 500 kg ha^{-1}, that it takes years before they actually influence N fluxes in grassland (Van der Meer & Van Uum-van Lohuyzen, 1986; Neetson et al., 1991). It should also be noted that net accumulation is a calculated balancing item and has no experimental background (Subsections 2.2.3 and 2.2.6). Therefore, the results from GRASMOD as presented in Figure 3.1 have not been adjusted to an equilibrium situation.

Net P accumulation (Figure 3.2b) is negative for all grassland utilization methods over the whole range of N application rates, as neither slurry nor fertilizer P is applied. P application is covered in the IMGLP model. Under zero grazing all herbage is transported indoors, resulting in a large export of P from the field. Under day grazing part of the P is excreted again on the pasture and under day-and-night grazing only a small part of the P is collected in slurry indoors.

If herbage for conservation is cut at 3 000 kg DM, it is either ensiled or dried artificially. Harvest and conservation losses for ensiling and artificial drying are 15 and 5 %, respectively. If herbage is cut at 4 000 kg DM it is ensiled or made into hay, associated with harvest and conservation losses are 15 and 35 %, respectively (Figure 3.3).

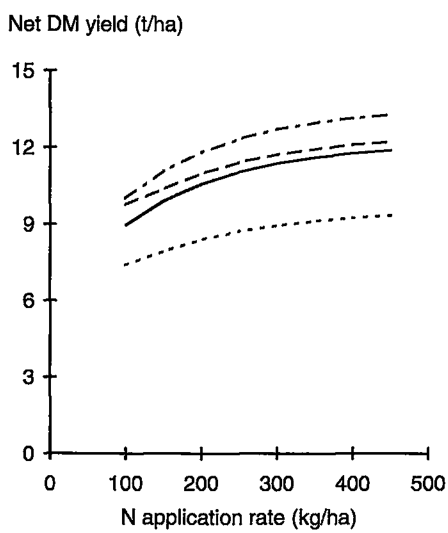

Figure 3.3. The relationship between N application and net herbage production as calculated with GRASMOD for conserved grass; hay (- - -), silage 3 t per cut (——), silage 4 t per cut (– – –), artificially dried grass (– · – · –).

The relationships between N application and nitrate and ammonia losses for grassland intended for herbage conservation are similar to those under zero grazing, as they depend on the N application rate and not on herbage production level. Net herbage produced forms an input for the winter rations of the cattle. The winter ration is composed in the IMGLP model. Hence, the ratio of the area used for summer and winter feeding is a result of the IMGLP model.

3.2. Herbage supply level

The herbage supply level only applies to dairy cows and not to young stock (Subsection 2.1.1). The main influences of herbage supply level on grass and milk production are given in Figure 3.4.
Again the results are presented per ha grassland for dairy cows producing 6 500 kg milk per year and an N application rate of 250 kg ha^{-1} yr^{-1}. Milk production decreases with increasing herbage supply level (Figure 3.4a). At a herbage supply level of 0.8 maximum milk production is 25.8 t ha^{-1} under zero grazing with maize supplementation. At a herbage supply level of 1.0 maximum milk production is 20.6 t ha^{-1}. Under day-and-night grazing, milk production is lowest and varies between 11.0 and 13.8 t ha^{-1}.
Stocking rate at a low herbage supply level is higher than at a high herbage supply level, and hence, slurry production too. Under day grazing and day-and-night grazing the amount of urine voided in the pasture increases with stocking rate. However, the N concentration in concentrates is lower than that in grass, especially for low-nitrogen concentrates, resulting in a lower N intake and N excretion per cow at a low herbage supply level. Figures 3.4b and 3.4c show the overall effect: nitrate losses are hardly influenced by the herbage supply level, and the difference in ammonia volatilization is only 2 to 3 kg ha^{-1}.
Concentrate purchases decrease with increasing herbage supply level (Figure 3.4d). N accumulation under grazing is higher at a low herbage supply level due to the higher stocking rate and concentrate inputs, but the influence of herbage supply level is small (Figure 3.4e).

3.3 Milk production per cow

Stocking rate decreases with increasing milk production per cow (Figure 3.5a) due to the higher energy requirements per cow. The stocking rates are high because they are expressed per ha grassland used in summer. Young stock and herbage conservation for the winter period are not included. Milk production per ha increases with increasing milk production per cow (Figure 3.5b).

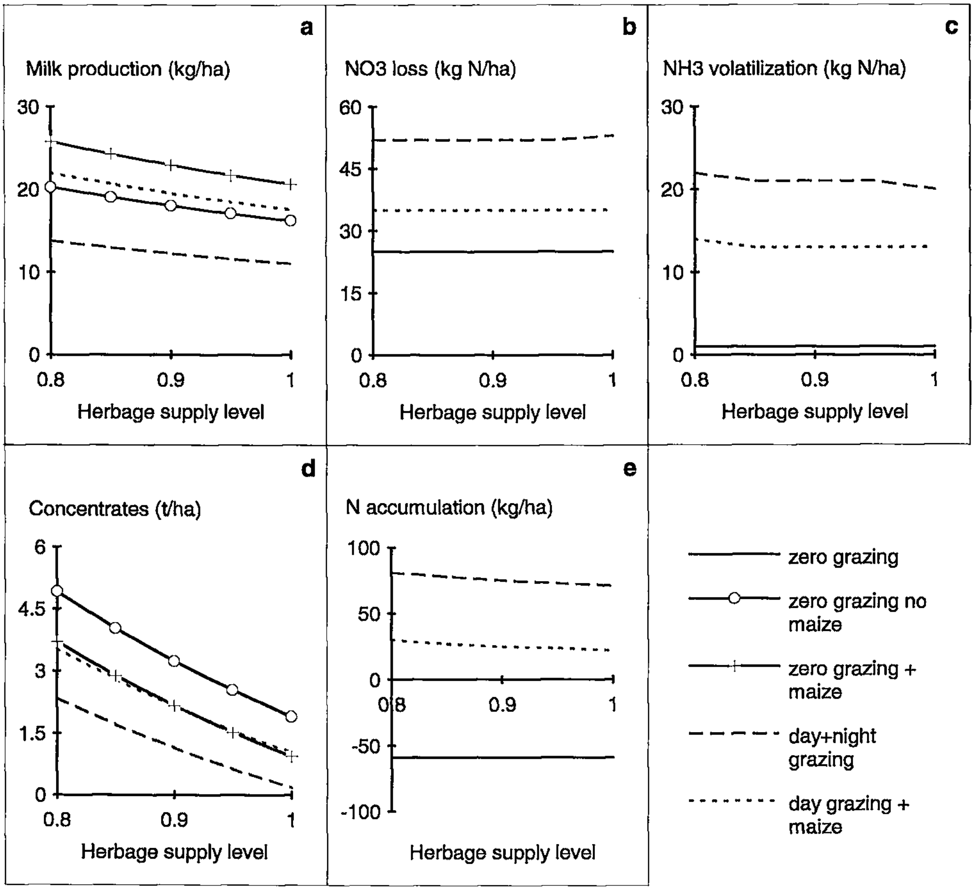

Figure 3.4 The relationship between herbage supply level and milk production (a), nitrate loss (b), ammonia volatilization (c), purchased concentrates (d) and net N accumulation (e) as calculated with GRASMOD for various grassland utilization methods.

The lower stocking rate is more than compensated for by the higher milk production per cow. Milk production per ha under zero grazing without maize supplementation increases relatively more than under the other grassland utilization methods. Table 3.3 shows that under zero grazing without maize supplementation the additional milk production per cow is mainly achieved by increasing the concentrate input, while under zero grazing with maize supplementation, it is mainly brought about by increasing the herbage input per cow. Net herbage production is identical in both systems. Hence, in the latter system the stocking rate decreases more than in the former system. Under day-and-night grazing and day grazing, herbage intake also increases more than concentrate intake. The effect of milk production per cow on nitrate losses

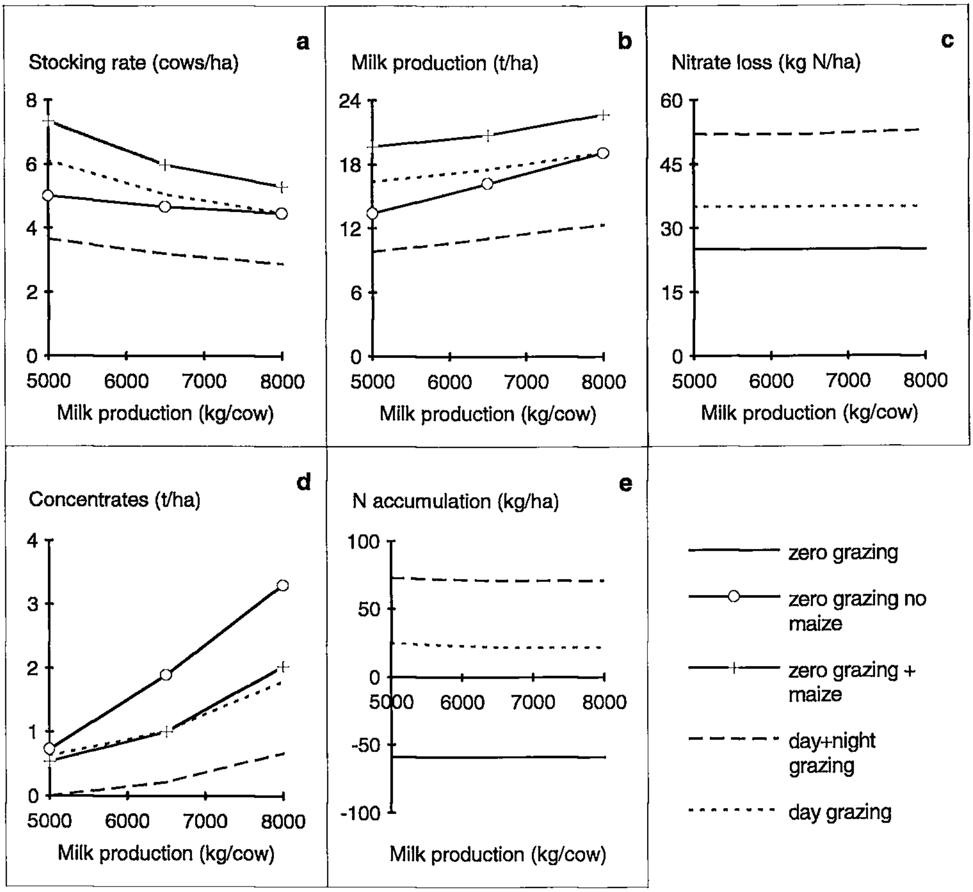

Figure 3.5 The relation between milk production level per cow and stocking rate (a), milk production per ha (b), nitrate loss (c), purchased concentrates (d) and net N accumulation (e) as calculated with GRASMOD for various grassland utilization methods.

Table 3.3 The daily ration in kg cow^{-1} d^{-1} for dairy cows producing 5 000 and 8 000 kg milk yr^{-1} under zero grazing with and without maize supplementation.

Feed	5 000		8 000	
	- maize	+ maize	- maize	+ maize
Grass	12.0	8.2	13.4	11.3
Maize	0	4.5	0	4.5
Concentrates	0.8	0.4	4.0	2.1
Total DM intake	12.8	13.1	17.4	17.9

per ha is negligible. Apparently, the larger amount of N excreted in urine per cow offsets the decrease in stocking rate (Figure 3.5c). Ammonia volatilization per ha also hardly varies. The required amount of concentrates per ha increases with increasing milk production (Figure 3.5d). N accumulation per ha hardly varies with milk production level (Figure 3.5e).

3.4. Comparison of results from GRASMOD with measured field and farm data

GRASMOD applies to an average situation on well-drained sandy soils (Subsection 2.2.1). Therefore, it is difficult to compare model results with the results of experiments at specific locations.

If the relationships between N application, N uptake and herbage yield are known for a given location, these should be entered in GRASMOD. On soils with a productive capacity similar to the soil defined in GRASMOD, the calculated annual herbage yield should agree with the measured yield. The extremes to herbage yield in GRASMOD are determined by harvesting consistently at 1 700 and at 4 000 kg DM (Figure 3.6). In experiments in Den Ham and Ruurlo data on yield, N uptake and N application per cut were available for 5 years (Snijders et al., 1987). The average annual yields were similar to those from PAW 970.

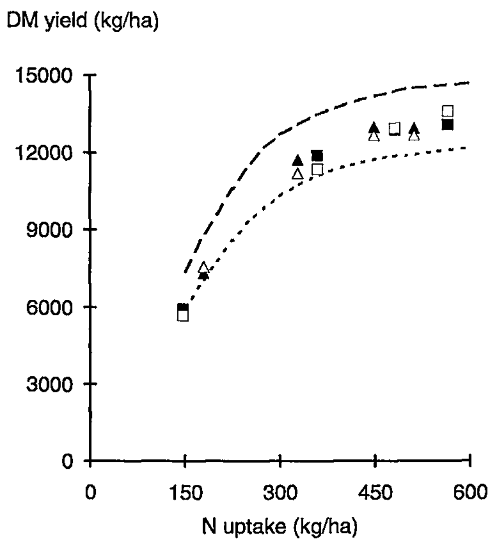

Figure 3.6 Calculated and measured herbage yield in relation to N uptake for two experiments on sandy soils and the limits on herbage yield in GRASMOD. Den Ham: measured Δ, calculated ▲; Ruurlo: measured □, calculated ■; GRASMOD:1.7 t per cut - - - , 4 t per cut – – – .

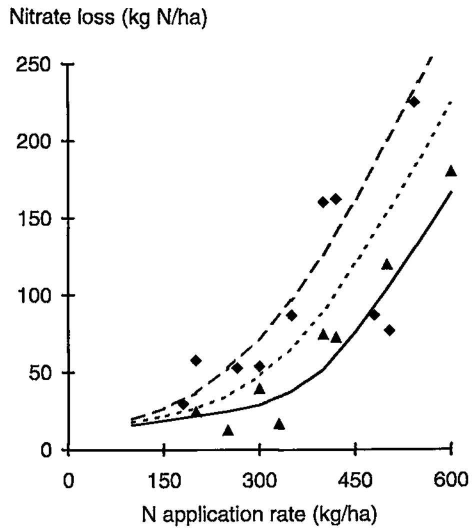

Figure 3.7 Calculated and measured effects of N application on nitrate losses. Zero grazing —— , day-and-night grazing – – – , day grazing - - - -, measured grazing ♦, measured cutting ▲.

Average annual herbage production was calculated with GRASMOD from the number of cuts of 1 700, 2 300, 3 000 and 4 000 kg and total annual N uptake. The calculated yields were in good agreement with measured ones (Figure 3.6).
Figure 3.7 shows experimental data on nitrate losses under grazing from Steenvoorden et al. (1986) and Garwood & Ryden (1986). The calculated and measured nitrate losses under grazing are in the same order of magnitude.
Another question is how herbage production calculated in GRASMOD compares to well-managed commercial farms. This is hard to establish, as herbage production and N uptake are not measured on farms. GRASMOD has been expanded to farm level by adding modules for maize production according to Aarts & Middelkoop (1990) and feeding in winter (Van der Putten & Van der Meer, 1995). The farm model has been applied to nine farms with a different milk production per ha in the south of the Netherlands (Van der Putten & Van Laarhoven, 1994). N application, grassland utilization method, purchase of slurry, stocking rate, milk production and the area under maize were used as input data. Roughage production was unknown. From the N application rate, herbage production according to GRASMOD and maize production according to the maize module, were calculated. Concentrate and roughage purchases and sales have been calculated according to the farm model. The total feed input according to feeding standards and the actual feed input are compared in Figure 3.8. It should be noted that the farm data refer to the year 1991 only.

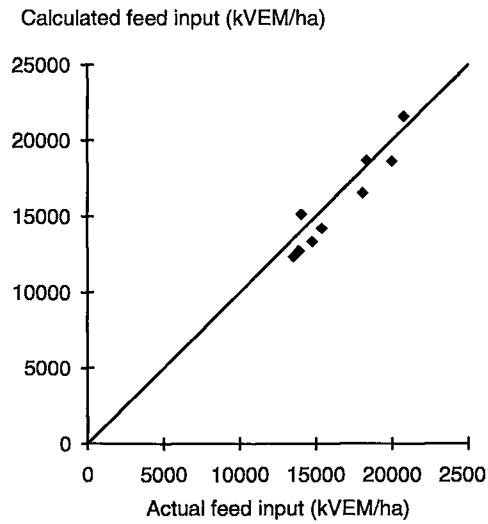

Figure 3.8 Comparison of the actual and calculated feed inputs for nine farms in the south of the Netherlands (After: Van Putten & Van Laarhoven, 1994).

According to this figure, six out of the nine farmers fed about 10 % above the feeding standard, two just below and one at the standard. However, it is impossible to establish the causes. On some farms, actual concentrate input exceeded the standard. However, they may have fed according to the feeding standard, but did not achieve the calculated roughage production. The model is aimed at realization of attainable yield levels (Rabbinge, 1993). Good grassland management and timeliness of operations was assumed, which may not have been possible in practice. Moreover, feeding according to the standard does not automatically imply standard milk production, as there is a wide variation in feed conversion among animals. Hence, it is very difficult, if not impossible, to validate the model accurately due to lack of data. However, Figure 3.8 shows that the calculated and observed total feed inputs agree reasonably well.

3.5. Conclusions

In this chapter is has been shown that grassland utilization method and N application level have a large influence on N flows in grassland. The influence of herbage supply level and milk production level per cow mainly influence the concentrate purchases and to a smaller extend also milk production per ha. The technical coefficients for grass production and utilization techniques as used in the IMGLP model have been based on the relationships presented in this

chapter. All the effects described in Sections 3.1 - 3.3 apply to one ha grassland used for feeding in summer. Results per ha cannot be extrapolated to farm level, as other aspects have to be taken into account, such as the area cultivated with maize, slurry application, the winter ration, the proportion of young stock raised on the farm, etc.
It is difficult to validate the model properly. Comparison with field experiments and farm results have not revealed large deviations.

4. Cultivation of maize and fodder beets

Land can also be used for the cultivation of other fodder crops than grass, in this study maize and fodder beets have been included. Therefore, Technical Coefficient Generator (TCG) models similar to GRASMOD, were also developed for maize and fodder beet. By adding maize to a protein-rich ration for dairy cows, the overall utilization of dietary N by the animal increases due to a more favourable ratio between energy and protein supply (Van Vuuren & Meijs, 1987; Van Vuuren et al., 1993). Cultivation of ground ear silage and fodder beets offers the opportunity to produce concentrates within the region and thus reduce imports.

Maize can be grown continuously, but fodder beets have to be cultivated in rotation with other crops. A rotation of one year fodder beet and two years maize was chosen in this study.

The production techniques for maize and fodder beets have been defined in a target-oriented way, i.e. a production target is set first and various ways of reaching that target are defined. N losses under maize are often substantial (Van Dijk,1985; Schröder & Dilz, 1987, Schröder et al., 1992). They may be reduced by lowering the N application rate and through crop husbandry measures. A lower N application rate results in a lower yield and a lower N concentration in the crop. As the main characteristic of maize for inclusion in the ration of dairy cows is its low N concentration, combined with a high energy content, N concentration was selected as the target. Three target values have been defined: 11, 12 and 13 g N kg^{-1} on a whole plant basis, associated with to 85, 90 and 95 % of the maximum attainable yield (Section 4.2). Nitrate losses under fodder beets are generally low (Subsections 4.4.2 and 4.5.2). Hence, a variation in N application rate and N concentration are of less concern than for maize. For fodder beets, only one target yield was defined, i.e. the maximum attainable yield of 22 t ha^{-1} (Section 4.2).

In the following section the characteristics of the production techniques for maize and fodder beets are described. To quantify their inputs and outputs, the relationships between N uptake and yield, N application and uptake, and N application and losses are required. These are described in subsequent sections. In the final sections the results of the TCG for maize and fodder beet are briefly discussed.

Table 4.1 Definitions and numerical values of the indices of fodder production techniques.

S	Production target maize	Production target fodder beet
1	13 g N kg^{-1}	22 t ha^{-1}
2	12 g N kg^{-1}	22 t ha^{-1}
3	11 g N kg^{-1}	22 t ha^{-1}
N	Inorganic fertilizer	Slurry
1	100 %	0 %
2	75 %	25 %
3	50 %	50 %
4	0 %	100 %
A	Slurry application method	Volatilization, % of NH3-N
1	injection	5
2	ploughing within one day	25
3	surface spreading	60
R	Inorganic fertilizer	Slurry
1	broadcast	broadcast
2	broadcast	row
3	row	broadcast
4	row	row
L	Fate of fodder beet leaves	
1	harvested and fed to animals	
2	left in the field after harvest	
W	Catch crop after maize	
1	no	
2	yes	
Q	Product	
1	whole plant maize silage	
2	ground ear silage	

4.1. Characteristics of the production techniques

The production target, either the N concentration for maize or the dry matter yield for fodder beets, can be realized in various ways, each of which is defined as a separate production technique. Such a production technique is characterized by the production target (S), the ratio between inorganic fertilizer and slurry application in terms of total N supply (N), the slurry application method (A), the method of fertilizer application (R), the fate of fodder beet leaves (L), growing a catch crop or not (W) and the type of maize product harvested (Q). The definitions and the values of these indices are given in Table 4.1.

The production techniques were defined for a well-drained sandy soil with a good water-holding capacity, similar to the grass production techniques. The water supply to grass, in addition to rainfall, was 160 mm yr^{-1}. As soil organic matter content decreases after ploughing up the grassland, the water-holding capacity also decreases somewhat.

Under average Dutch weather conditions, maximum yield of maize, as determined by soil water supply, is 14.8 tonnes ha^{-1} at a soil water supply of 125 mm and 15.3 tonnes ha^{-1} at a soil water supply of 175 mm (Aarts & Van Keulen, 1990). In the TCG for maize a maximum yield of 15 tonnes ha^{-1} has been assumed, corresponding to a soil water supply of about 150 mm.

Under average Dutch weather conditions, maximum dry matter yield of a fodder beet crop, including both leaves and roots, at a soil water supply of 175 mm is about 25 t ha^{-1} (Aarts & Van Keulen, 1990). At a water supplying capacity of 150 mm, the maximum yield level is estimated at 22 t ha^{-1}.

The ratio of inorganic fertilizer and slurry affects the amount of organic matter applied annually. Four ratios have been defined in this study.

The method of slurry application determines ammonia volatilization losses and hence the amount of N available for uptake by the crop. Three methods of slurry application were considered, i.e. injection, which places slurry at a depth of about 10 cm, with a low risk of ammonia volatilization, surface spreading immediately followed by incorporation into the soil with a moderate risk of volatilization, and surface spreading only with a high risk of volatilization (Mulder & Huijsmans, 1994). The first two techniques comply with recent legislation in the Netherlands, aimed at reducing ammonia volatilization.

Placing of fertilizer close to the plant rows increases the apparent N recovery. Placement is not restricted to inorganic fertilizers, but also applies to slurry, i.e. injection prior to planting. It was demonstrated recently that for both inorganic (Maidl, 1990; Maddux et al., 1991; Schröder, 1991) and slurry (Sawyer et al., 1991), N placement of the fertilizer increases maize yield. For sugar beet the N recovery was increased by placement of inorganic fertilizer (De Wit, 1953). The effect of slurry placement was small, but this refers to experiments in which the soil was N-rich and slurry application was high (Van der Beek & Wilting, 1991). It was assumed that the effect of placement on recovery of inorganic N in slurry is identical to that for inorganic N fertilizers.

For row fertilization a band width of 5 to 10 cm would be appropriate for small amounts. At higher application rates, about a quarter of the area between the rows should be fertilized to prevent salt damage:

$$Xr/Xb = 0.25$$

where: Xr = width of the fertilizer band

Xb = row distance

At an N recovery of 65 % for broadcast application (Rb), the recovery for row fertilization (Rr) will be (De Wit, 1953):

$$Rr = \frac{100 * \left(\frac{Xb}{Xr}\right)^{0.56} * Rb}{100 + \left(\left(\frac{Xb}{Xr}\right)^{0.56} - 1\right) * Rb} = \frac{100 * 2.2 * Rb}{100 + 1.2 * Rb} = 80\ \%$$

At an annual application rate of 100 kg N ha^{-1}, uptake from broadcast fertilizer (Ub) will 65 kg N ha^{-1}. To realize the same uptake from fertilizer placed in rows, an application rate of 80 kg ha^{-1} will suffice.

Growing catch crops, such as winter rye or grass, results in partial transformation of residual inorganic soil N into organic forms until the next growing season, thus reducing nitrate leaching during the winter period. The subsequent maize crop can take up part of this N. This leads to improved overall N utilization, if the remineralization pattern coincides with the uptake pattern of the subsequent maize crop and the application rate in the following season is reduced accordingly. Catch crops took up 35-85 kg N ha^{-1} yr^{-1} in a three-year field experiment on sandy soil (Schröder et al., 1992). In these experiments, early harvest of the maize and timely established catch crops were aimed at, to provide favourable growing conditions for the latter. The experimental results may have presented too favourable a picture due to the mild weather conditions during the winters, hence measured N storage by the catch crops may represent potential values rather than averages. In the TCG, representing average conditions, a catch crop is assumed to take up 40 kg N ha^{-1} which is subtracted from the total N loss. The crop is ploughed in early spring. Part of the

40 kg N is available to the maize crop, part is lost later, and part is added to the soil organic N pool. The average recovery of N supplied in the catch crop was estimated at 35 % (11-63 %, Schröder & Ten Holte 1992; Schröder et al., 1992). Growing a catch crop after fodder beet was not considered, because the amount of N left in the soil after harvest is rather low and the harvest is too late.

Maize can either be harvested for whole plant maize silage, from now on referred to as maize silage or ground ear silage. Ground ear silage consists of the grains, the cob, the husks and the shank of the maize plants. Cultivation of maize silage and ground ear silage is similar, but ground ear silage is harvested at a later stage of development and consequently at a higher dry matter content (50 % for ground ear silage and 30 % for maize silage). The consequences of the later harvest date of ground ear silage for the catch crop are not accounted for. The type of product harvested, often depends on weather conditions in autumn. For ground ear silage, the weather in summer should favour timely flowering, grain setting and grain filling and the weather in autumn, early maturation. Ground ear silage comprises 60 % of the standing crop on a dry matter basis, compared to 100 % for maize silage (Van Dijk, 1993). The proportion that can be harvested as ground ear silage is constant, if N is the main production-limiting factor. If water availability is limiting, a relatively smaller part of the dry matter is allocated to the ear and the relative yield of ground ear silage will thus be lower. The amount of stover left after harvesting ground ear silage is larger than after harvesting maize silage. At an overall N concentration of 13.0 g kg^{-1}, the N concentration of ground ear silage is about 14.7 g kg^{-1} (Van Dijk, 1993; Schröder, unpubl.) and that of the stover 10.3 g kg^{-1}. At an overall N concentration of 12 and 11 g kg^{-1}, these values are 13.6 and 9.5, and 12.5 and 8.9 g kg^{-1}, respectively. The stover is left in the field and contributes to soil organic matter.

The leaves of fodder beets can either be left in the field after harvest and added to the soil organic matter or they can be removed and fed to the animals.

Each combination of the indices S, N, A, R, L, W and Q defines a specific production technique, XM(S,N,A,R,W,Q) for continuous maize cultivation and XB(S,N,A,R,L,W,Q) for the rotation of fodder beet and maize. However, not all combinations are relevant.

For each production technique inputs and outputs have been quantified on the basis of the TCG. Inputs are inorganic fertilizer, slurry, land, seed, labour and machinery. Outputs are amount and quality of the product and N losses by leaching, denitrification and volatilization.

It is assumed that fodder crops are cultivated using the 'best technical means'. This includes slurry application in April, appropriate seed-bed preparation, effective weed control, etc.

4.2. Nitrogen uptake and crop production

The relationship between N uptake (U, kg ha^{-1}) and dry matter yield (Y, kg t^{-1}) is described by a non-orthogonal hyperbola (Aarts & Middelkoop, 1990; Figure 4.1).

$$-A*Y^2 + U*Y + B*Y + C*U = 0$$

The parameters A, B and C describing this function are calculated from the minimum N concentration, defining the initial slope of the curve (C/B), a shape parameter (A*C/B) and the maximum attainable yield (C/f). The minimum N concentration is species and cultivar-specific, but does not depend on growing conditions. The shape parameter is derived from the results of field experiments (Aarts & Middelkoop, 1990). The maximum yield is determined by water supply. The value C of the asymptote is somewhat above the maximum attainable yield, as by definition, the asymptote cannot be reached. The factor f is derived from field experiments. The term 'maximum yield' as used in this study, refers to the yield that can actually be attained in the field.

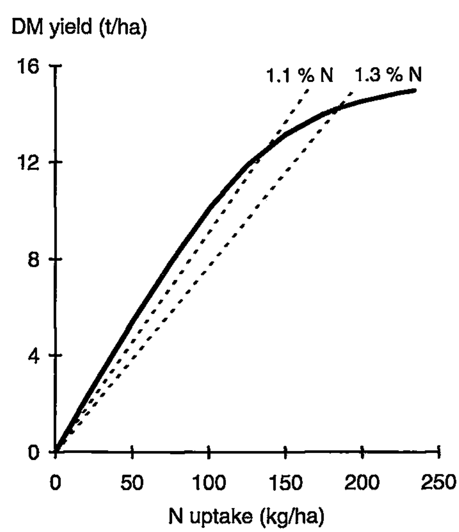

Figure 4.1 The relationship between N uptake and maize dry matter yield as used in the TCG.

The relationship between N uptake and maize dry matter yield at a water supply capacity of 150 mm is shown in Figure 4.1. For maize the minimum overall N concentration is approximately 9 g kg^{-1} (Aarts & van Keulen, 1990). At the target N concentrations of at 11, 12 and 13 g kg^{-1}, N uptake is 140, 165 and 185 kg ha^{-1}, respectively. The associated dry matter yields are 12.7, 13.7 and 14.3 tonnes ha^{-1}, respectively, i.e. 85, 91 and 95 % of the maximum yield of 15 t ha^{-1}.
It was assumed that the response of fodder beet to N is similar to that of sugar beet, as both crops are essentially the same. By breeding for a high sugar content, sugar beet was developed from fodder beet. The results of experiments on sugar beet have been used where necessary, as very few experiments have been carried out with fodder beet.
For fodder beet the yield calculated from the non-orthogonal hyperbola includes both roots and leaves. The minimum N concentration of the whole crop is approximately 6 g kg^{-1}. The maximum attainable yield is 22 t ha^{-1} at an N uptake of 265 kg ha^{-1}. The relationship between N uptake and crop production is given in Figure 4.2.
The ratio between root and leaf dry matter in fodder beet at harvest decreases with increasing N uptake. Thus, at higher N application rates relatively more dry matter is allocated to the leaves. Based on field experiments the root:leaf ratio,

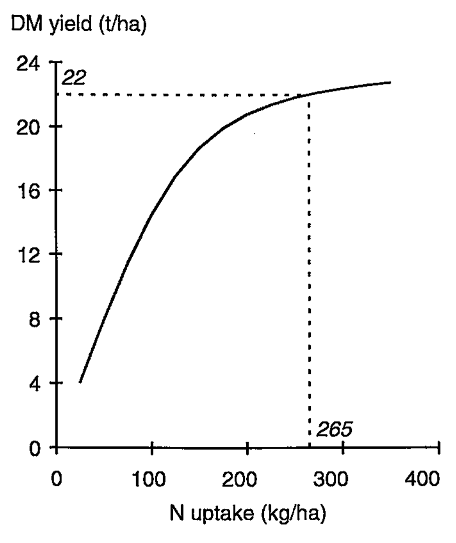

Figure 4.2 The relationship between N uptake and total dry matter yield of a fodder beet crop as used in the TCG.

on a dry matter basis, is 85:15 at an N uptake of 100 kg ha^{-1} and 75:25 at an N uptake of 350 kg ha^{-1} (Houba, 1973; K.U. Leuven et al., 1985; Westerdijk, 1992; Baan Hofman & ten Holte, 1992). N distribution between roots and leaves was derived from the same experiments. Up to an N uptake of about 200 kg ha^{-1} the proportion of N allocated to the root is fairly constant: 50-60 %. At higher N uptake rates, the ratio remains the same in some trials, while it decreases in others. Since the data are ambiguous, a constant value of 55 % has been assumed in this study.

4.3. Nitrogen fluxes in the soil-crop system

To realize the required N uptake, N has to be applied in amounts depending on the supply of N from decomposition of soil organic matter and deposition, and on the apparent recovery of the added N. Wolf et al. (1989) developed a model describing N transformations in the soil-crop system in a way which is well suited for the quantification of N flows for the purposes of this study.

The model is a simple mass balance model, which systematically describes the main transformations. It uses time steps of one year. Long-term changes in soil organic N and the required N supply to achieve the production target are calculated.

N may be added to the soil from external sources, such as deposition, inorganic fertilizer and organic materials. Inorganic N is partitioned between crop uptake and losses from the system. Net incorporation of inorganic N into organic matter is assumed to be small, because it is likely that the soil in the Netherlands has been accumulating N over the past decades and is more or less in equilibrium (Van der Meer & Van Uum-van Lohuyzen, 1986). However, some immobilization due to the high C/N ratio of crop residues and microbial biomass is unavoidable.

In the model a stable and a labile pool of soil organic N are defined as SON and LON, respectively. N added in organic form is partitioned between crop uptake, losses and labile organic matter. The part of the added organic N that becomes available in the year of application, is treated similarly to inorganic N. Mineralization is assumed to occur from the labile pool only and depletion of the stable pool occurs by transfer to the labile pool. Part of the labile organic matter is converted into stable organic matter. Table 4.2 provides an overview of the partitioning (or transfer) coefficients to be specified.

These transfer coefficients have been estimated for maize and fodder beet cultivation on well-drained sandy soils. If no specific data for these conditions were available, the estimates of Wolf et al. (1989) were used.

Table 4.2 Transfer coefficients required to run the model.

Input	Transfer coefficients to:			
	Crop	Loss	Labile pool	Stable pool
Inorganic fertilizer	+	+	+	
Deposition	+	+	+	
LON	+	+	+	+
SON			+	
Stover	+	+	+	
Catch crop	+	+	+	
Slurry	+	+	+	

4.3.1. Transfer coefficients for maize

The apparent recovery of inorganic N fertilizers largely depends on the weather conditions, i.e. in a wet and cold year recovery is lower than in a warm and dry year. Moreover, root extension in spring is slow and the row distance is large. The apparent recovery in harvested products in an average year is estimated at about 50 %, however, the variation is considerable (Schröder, 1991; Schröder et al., 1992).

The root biomass left after harvest is 1 000 to 3 000 kg ha^{-1}. The shoot:root ratio increases with increasing fertilizer rate, but the absolute root biomass hardly changes with increased fertilizer application (Schröder & ten Holte, 1992). Therefore, it has been assumed that irrespective of above ground yield, a crop forms 2 500 kg roots ha^{-1} with a N concentration of 7 g kg^{-1} (Schröder et al, 1992). Thus, the roots contain 18 kg N ha^{-1}. Stover weight after harvest is 300 kg ha^{-1} for silage maize. The N-concentration is 9.5 g kg^{-1}. This means that 3 kg N ha^{-1} is incorporated in the stover.

In balance studies in various maize experiments, Schröder (1991) found that 16-40 % of the total amount of spring applied mineral N was not accounted for by crop uptake or soil inorganic N in autumn. This suggests that substantial losses may occur during the growing period. Based on these observations, it is estimated that 65 % of the inorganic N applied is taken up by the crop in both above ground biomass and in the roots, 5 % is incorporated in LON (immobilization in microbial biomass due to the high C/N ratio of the stover) and that the remaining 30 % is lost. As this is largely characteristic of the local conditions, this ratio has been applied to all inorganic N sources available during the growing season (Table 4.3).

Table 4.3 Transfer coefficients used in the TCG for maize.

			Available	Crop	Loss	LON	SON
Inorganic fertilizer			1.00	0.65	0.30	0.05	
Deposition			0.60	0.39	0.18 + 0.40	0.03	
LON			0.85	0.44	0.37	0.04	0.15
SON						1.00	
Stover			0.30	0.18	0.011	0.01 + 0.70	
Catch crop			0.50	0.32	0.15	0.03 + 0.50	
Slurry	Nm	(0.50)	1.00	0.65	0.30	0.05	
	Norg	(0.50)	0.30	0.16	0.13	0.01 + 0.70	

Table 4.3 presents an overview of all transfer coefficients as estimated for maize on a well-drained sandy soil. The first column gives the fraction of the input source available during the growing season. This N is divided between uptake by the crop, LON and losses in a ratio 65:5:30. The complement is lost or immobilized. Therefore, in some cases the transfer coefficients for losses and LON consist of two terms.

Maize takes up N during a limited part of the growing season only. Therefore, not all N available throughout the year can be taken up by the crop. Based on the assumption that deposition is evenly distributed over the year, the fraction available to the crop is estimated at 0.6 (Lammers, 1983; Middelkoop & Aarts, 1991). This is divided between crop uptake, LON and loss in the ratio 65:5:30.

Due to its temperature sensitivity, mineralization during the growing season is higher than in winter. About 15 % of the mineralized N is incorporated in the stable pool (Wolf et al., 1989) and 85 % is partitioned between crop uptake, LON and loss. As mineralization is not perfectly synchronized with crop uptake, it has been assumed that 80 % (Lammers, 1983) effectively becomes available. The remaining 20 % is lost. All N becoming available from SON is first transferred to LON, and then becomes available to other processes.

In temperate zones, about 70 %, on average, of the N applied in organic material, such as straw and roots, is partitioned to the labile pool. It may vary, however, from almost 100 % for material with a relatively low N concentration to 50 % or less for material with a high N concentration (Wolf et al., 1989). For the stover, a value of 70 % is applied and for a catch crop, with a much higher N concentration, a value of 50 % (Table 4.3).

On average, 50 % of the N in slurry is present as ammonia, and thus readily available to the crop (Nm), 50 % is present in organic form (Norg), of which

30 % mineralizes during the first 6 months following application and the remaining 70 % later (Westhoek & Noij, 1992). As slurry is applied in April, the fraction Nm is considered to react similarly to inorganic fertilizers and hence, the same transfer coefficient is applied. In August and September maize hardly takes up any more N (Schröder, 1992). Thus, the fraction of available N in Norg is reduced by 20 % and added to the N losses (Lammers, 1984; Middelkoop & Aarts, 1991). The transfer coefficients of inorganic fertilizer are applied to the remaining 80 %. The fraction not becoming available during the first 6 months, is fully added to the labile pool.

4.3.2. Transfer coefficients for fodder beet

The transfer coefficients describing N transformations in the soil under fodder beet were derived from field experiments similar to those for maize.

The apparent N recovery of inorganic fertilizers in the above ground biomass in an average year is about 70 % (Prins et al., 1988; Poccock et al., 1990). However, the N incorporated in decaying leaves and small roots is not accounted for in this figure. At low N application rates, up to 50 % of the total weight of leaves produced dies during the growing season, while at high N application rates this fraction is smaller (Houba, 1973). The minimum N concentration in dead leaves was about 14 g kg^{-1} and increased to about 25 g kg^{-1} at high application rates. Although leaves consist of easily decomposable organic matter, the N seems not to be available for uptake by the crop, as indicated by the rather low apparent N recovery and the small amount of inorganic N present in the soil after harvest. This indicates the incorporation of N in soil organic matter, possibly by soil microbes, or loss due to denitrification. The other sink for N not accounted for in the apparent N recovery, is that of the small roots left in the soil after harvest, representing about 5 % of the root dry weight (Van Egmond, 1975). Fodder beets take up N until the end of the season. The amount of N mineralized after harvest will generally be low, because fodder beets are harvested in late autumn.

Based on these considerations, it is assumed that the apparent N recovery for the whole crop, including beet, small roots and living and dead leaves, is 90 %. Part of the N taken up by the crop is added to the soil organic N pool by the leaves dying during the growing season. N in dead leaves is added to LON, the amount depending on total crop production and N uptake (Section 4.2). Immobilization of inorganic N is assumed to be 5 %, as for maize. Hence, the transfer coefficients of inorganic N to crop and LON are variable, but add up to 0.95. For the example in Table 4.4, the transfer coefficient to the crop has been set at 0.8 and at 0.15 to LON.

The fraction of the N deposition available to the crop is higher than for maize, as fodder beets take up N over an extended part of the season. This fraction is estimated at 0.7 (Lammers, 1983; Middelkoop & Aarts, 1991). The transfer coefficient from the labile to the stable pool is assumed to be equal to that for maize (0.15). Of the remaining 85 %, the fraction of N available to the crop during the growing period has been estimated at 0.9 (Lammers, 1983; Middelkoop & Aarts, 1991). This is partitioned between uptake, LON and loss in the ratio 80:15:5.

Although the leaves left after harvest are easily decomposable, no accumulation of inorganic N and hardly any additional leaching was measured during winter (Baan Hofman & Ten Holte et al. 1992; Van Erp et al., 1993; Ten Holte, pers.comm.). About 4 years after beet cultivation N uptake without fertilizer application was higher when the leaves were not harvested, but ploughed in (Drebuck, 1979). Calculated mineralization from November to March varied from 10-20 kg N ha^{-1} for sugar beet leaves (Catalan & Janssen, in prep.) and 5-10 kg N ha^{-1} for total sugar beet residues with a C:N ratio of 19 (Van Erp et al., 1993). Crop residues of fodder beet mainly consist of leaves and have a C:N ratio of about 12 (Debruck, 1979), leading to a higher degree of N mineralization (Van Erp et al. 1993). Hence, a value of 10-20 kg N ha^{-1} becoming available in winter and subject to leaching seems reasonable. The N incorporated in fodder beet leaves according to the TCG is 120 kg ha^{-1}. The nitrate loss was assumed to be 10 % of this amount, i.e. 12 kg N ha^{-1}. The direct transfer from leaves to LON was set at 0.6, halfway between a catch crop and maize stover, and 0.4 is partitioned between crop, loss and LON.

An overview of the transfer coefficients for fodder beet cultivation is given in Table 4.4

Table 4.4 Transfer coefficients used in the TCG for fodder beets.

			Available	Crop	Loss	LON	SON
Inorganic fertilizer			1.00	0.80	0.05	0.15	
Deposition			0.70	0.56	0.04 + 0.30	0.10	
LON			0.85	0.60	0.12	0.13	0.15
SON						1.00	
Leaves			0.36	0.29	0.02 + 0.10	0.05 + 0.54	
Slurry	Nm	(0.50)	1.00	0.80	0.05	0.15	
	Norg	(0.50)	0.30	0.24	0.02	0.04 + 0.70	

4.3.3. The phosphorus balance

For phosphorus (P), the outputs of each production technique have been quantified, by multiplying crop yield exported from the field with its P concentration. The P concentration in maize silage is 2.2 g kg^{-1}, in ground ear silage 3.2 (Van Dijk, 1993, Asijee, 1993; Schröder, pers. comm.), in fodder beets 2.0 and in beet leaves 3.5 (Biewinga et al., 1992). P inputs consist of deposition, estimated at 1 kg ha^{-1}, slurry; containing 0.78 kg P t^{-1} (Asijee, 1993) and P fertilizer. It has been assumed that the P status of the soil is 'sufficient' in agricultural terms, i.e. a Pw value of 20-45 and that, to maintain this status, P output has to be covered by P input. Hence, the amount of P applied by slurry and fertilizer covers the difference between input and output. For high slurry applications, even without P fertilizer, there is a P surplus.

4.3.4. Model initialization

The data required by the model are the target N uptake, the magnitude of all external sources of N supply, apart from fertilizer application, the time constant of conversion of the labile pool and the initial size of the stable and labile pools. Target N uptake has already been set at 185, 165 and 140 kg ha^{-1} yr^{-1} at 13,12 and 11 g N kg^{-1} DM, respectively. N deposition was set at 45 kg ha^{-1} yr^{-1}.

The magnitude of each of the organic N pools separately cannot be assessed experimentally, as they do not represent physically or chemically distinct components. Hence, the sum is determined as equal to the total amount of soil organic N. Under permanent grassland the pools are supposed to be in equilibrium. It is assumed that the ratio of the time constants of the stable and labile pool is 1:20, resulting in an equilibrium ratio between the size of the stable pool and that of the labile pool of 3:1 (Wolf et al., 1989). The total amount of organic N in the upper 50 cm of the soil in the experiments on which GRASMOD is based, was 11 500 kg ha^{-1} or 0.0019 kg per kg soil (Van Soesbergen, unpubl. data). The sizes of the stable and labile soil N pool under permanent grassland are thus 8 625 and 2 875 kg ha^{-1}, respectively.

The time constant for decomposition of the labile pool may be derived from crop uptake in a non-fertilized situation (Wolf et al., 1989). Under grassland, 220 kg N was available as a result of decomposition, yielding a time constant of 13 years. Hence, the time constant of the stable pool is 260. This corresponds with annual relative mineralization rates of 0.076 and 0.0038.

As under maize, N inputs are lower and less organic matter accumulates than under grassland, the size of both the labile and the stable organic N pools will decrease. Thus, following the break up of grassland, a new equilibrium between both pools will gradually be established, governed by the inputs and outputs of

organic and inorganic N in the production technique. It has been assumed that the equilibrium ratio between the two pools does not change.
On sandy soils, continuous maize cultivation has grown tremendously since the early seventies, initially at the expense of both grass and arable cropping and more recently instead of grass only. Maize has thus been grown on the same fields for 20 to 25 years. The average results of the model by Wolf et al. (1989) from the 20^{th} to the 25^{th} year after breaking up grassland, have been used in the TCG for both continuous maize cultivation and rotation with fodder beet.

4.4. Results

The TCG models for maize and fodder beet have been run for all relevant combinations of the indices. The influence of each will be discussed briefly.
The relevant inputs and outputs of the TCG for this study comprise N uptake, above ground dry matter yield, inorganic fertilizer application (N and P), slurry application, nitrate losses, ammonia volatilization and P surplus. All figures in the following sections are expressed on an annual basis.

4.4.1. Results of the TCG for continuous maize cultivation

Table 4.5 gives some results of the TCG for continuous maize cultivation.
The first system in Table 4.5 is considered the reference system. In this system N concentration is 13 g kg^{-1}, inorganic fertilizer is broadcast, no catch crop is grown and the product is maize silage, yielding 14.3 t ha^{-1} and taking up 185 kg N ha^{-1}. To attain the target N concentration, 225 kg ha^{-1} of fertilizer N is required. The associated nitrate loss is 130 kg N ha^{-1} and no ammonia volatilizes, as only inorganic fertilizers are used. P fertilizer has to be applied at a rate of 30 kg ha^{-1} to maintain the P balance at zero. If inorganic fertilizer is replaced by the injection of slurry, 285 kg N ha^{-1} is required. At an average N content in slurry of about 4.4 kg t^{-1}, this amounts to 65 t ha^{-1}. Nitrate loss is 150 and ammonia volatilization 7 kg N ha^{-1}. The P surplus is 12 kg ha^{-1}. Hence, no additional P is applied.
Compared with the reference system, growing a catch crop reduces the required N application by 35 kg ha^{-1} and nitrate losses by 40 kg N ha^{-1}. If fertilizer is placed in the row, fertilizer requirements are 45 and nitrate losses 40 kg N ha^{-1} lower than in the reference system. However, nitrate losses are still very high. If a catch crop and fertilizer placement are combined, 155 kg N ha^{-1} is required and nitrate losses are 60 kg N ha^{-1}. If the crop is harvested as ground ear silage, the amount of N required is 40 kg lower than in the reference system, because the stover adds to the labile pool and thus more N becomes available via

Table 4.5 Some results of the TCG for various production techniques for maize.

Production technique	Code* XM(S,N,A,R,W,Q)	N rate kg ha^{-1}	NO_3 loss kg N ha^{-1}
Inorganic fertilizer only	XM(1,1,1,1,1,1)	225	130
Slurry only, injection	XM(1,4,1,1,1,1)	285	150
Catch crop	XM(1,1,1,1,2,1)	190	90
Row fertilization	XM(1,1,1,3,1,1)	180	90
Catch crop+row fertilization	XM(1,1,1,3,2,1)	155	60
Product ground ear silage	XM(1,1,1,1,1,2)	185	140
N concentration 12 g kg^{-1}	XM(2,1,1,1,1,1)	190	120
Catch crop	XM(2,1,1,1,2,1)	160	80
Row fertilization	XM(2,1,1,3,1,1)	155	85
Catch crop+row fertilization	XM(2,1,1,3,2,1)	130	55
Product ground ear silage	XM(2,1,1,1,1,2)	155	125
N concentration 11 g kg^{-1}	XM(3,1,1,1,1,1)	155	105
Catch crop	XM(3,1,1,1,2,1)	120	70
Row fertilization	XM(3,1,1,3,1,1)	125	80
Catch crop+row fertilization	XM(3,1,1,3,2,1)	100	45
Product ground ear silage	XM(3,1,1,1,1,3)	125	115

* for definition of the codes see Table 4.1

mineralization in subsequent years. Nitrate losses are 10 kg higher. The P fertilizer requirements are 26 kg ha^{-1}, i.e. 4 kg less than in the reference system, as more stover biomass remains in the field after harvest.

At an N concentration of 12 g kg^{-1}, N uptake is 165 kg ha^{-1}. To achieve that uptake, 190 kg ha^{-1} fertilizer N is required. The associated nitrate loss is 120 kg ha^{-1}. At an N concentration of 11 g N kg^{-1}, N uptake is 140 kg ha^{-1}. The required N fertilizer rate is 155 and the nitrate loss 105 kg ha^{-1}. The effects of the other measures on N application rate and nitrate loss are similar to those at the highest N concentration (Table 4.5).

On well-drained sandy soils, most of the N present in the soil profile in autumn leaches during the subsequent winter. Some denitrification may occur, depending on the availability of labile organic matter and oxygen and a favourable temperature, but is difficult to quantify. Denitrification has been estimated at about 10 % of the nitrate present in the soil in autumn (Steenvoorden, 1988; Boumans et al., 1989; Korevaar & Den Boer, 1990). Thus, the leaching losses for the various production techniques amount to 90 % of the nitrate losses as given in Table 4.5.

For all other relevant combinations, such as row fertilization and growing a catch crop combined with organic fertilizer, inputs and outputs have also been calculated. The results are interim to those presented in Table 4.5 and are therefore not further discussed here.

4.4.2. Results of the TCG for fodder beet

Table 4.6 presents some results of the TCG for cultivation of fodder beets, similar to those for continuous maize cultivation.

The first technique shown in Table 4.6 is the reference technique. N uptake is 265 kg ha^{-1}, beet yield 17.3 and leaf yield 4.7 t ha^{-1}. N concentration in beets and leaves is 0.8 and 2.5 g kg^{-1}, respectively. Only inorganic fertilizer is applied, which is broadcast, and the leaves are removed from the field. To attain the target yield, 295 kg ha^{-1} N fertilizer has to be applied. Nitrate losses are 40 kg N ha^{-1}. P application is 36 kg ha^{-1}. If inorganic fertilizer is replaced by slurry, 390 kg N is required, amounting to 89 t ha^{-1} and the nitrate loss increases to 55 kg N ha^{-1}. The P surplus is 19 kg and no additional P is applied. Row fertilization only reduces the inorganic fertilizer requirement by 15 kg N ha^{-1}, because the apparent N recovery is only slightly higher, i.e. 90 vs. 95 %. When the leaves are left in the field, the N fertilizer requirement is reduced to 275 kg ha^{-1}. In the first year after leaving the leaves in the field, the nitrate loss is 15 kg N ha^{-1} higher than under the reference system. In the second year it is 4 kg higher and in the third year 2 kg, i.e. total nitrate losses in the maize/fodder beet rotation are approximately 20 kg N ha^{-1} higher.

For fodder beet too, denitrification is estimated at 10 % of the nitrate loss, implying that 90 % of the nitrate loss is attributed to leaching.

For the 2:1 rotation of maize and fodder beet the same type of production techniques have been combined and weighted averages of the figures in Tables 4.5 and 4.6 were used in the optimization procedure.

Table 4.6 Results of the TCG for various fodder beet production techniques.

Production technique	Code* XB(N,A,R,L)	N rate kg ha^{-1}	NO_3 loss kg N ha^{-1}
Inorganic fertilizer only	XB(1,1,1,1)	295	40
Slurry only, injection	XB(4,1,1,1)	390	55
Row fertilization	XB(1,1,3,1)	280	30
Leaves left in field	XB(1,1,1,2)	275	55

* for definition of the codes see Table 4.1

4.5. Discussion

4.5.1. Maize production techniques

To calculate the technical coefficients of maize production techniques in this study, a target N concentration was defined, which was translated into a target N uptake. As maize takes up N during a limited part of the growing season, inorganic N available outside this period is lost. Table 4.3 shows that the ratio between N uptake and N loss is 68:32 for inorganic N fertilizer, 66:34 for slurry, 54:46 for N available from LON and 40:60 for N deposition. Hence, under the assumptions described above, maize uses N from inorganic fertilizer most efficiently. Nevertheless, the efficiency is low even for that source.

Nitrate losses are rather high. If inorganic fertilizer only is applied at a rate of 225 kg ha^{-1}, LON contains 1 100 kg N after 20-25 years. The total N concentration in the soil has decreased from 0.0019 to 0.0016 kg N kg^{-1} soil.

Annual N mineralization is 85 kg ha^{-1}, partitioned between crop uptake, loss, LON and SON in the ratio 44:37:4:15. Hence, nitrate losses from LON amount to 32 kg ha^{-1}. Nitrate losses from deposition and crop residues are 26 and 2 kg ha^{-1}, respectively. Hence, assuming that turn-over rates of LON and SON are constant and the previous land use was grassland, even without fertilizer application, nitrate losses will be 60 kg ha^{-1}. Assuming 10 % denitrification, 54 kg N is leached. This agrees very well with the data of Schröder & Dilz (1987), who estimated the nitrate leaching loss without fertilizer application to be 51 kg N ha^{-1} on a sandy soil with a N concentration of about 0.0013 kg kg^{-1}. Denitrification losses were not specified. In the reference system the nitrate loss from inorganic fertilizer is 70 kg ha^{-1}, leading to a total N loss of 130 kg ha^{-1}. The initial size of the organic N pool is rather large due to the preceding prolonged period of grass cultivation. Figure 4.3 shows the dynamics of the labile, the stable and the total soil N pool over 50 years for the reference production technique for maize, without organic amendments, and the technique with organic N inputs through the incorporation of slurry immediately after application. If inorganic fertilizer only is applied, the major decline in LON occurs during the first 20 years. The stable pool only declines very slowly, because of its low relative transformation rate (0.0038 yr^{-1}). Eventually, a new equilibrium situation will be reached, in which application of N equals export in harvested products and the ratio between stable and labile organic N pool is 3:1. The initial size of the organic N pool and the transfer coefficients of LON and SON only influence the rates of change, but not the final equilibrium situation. The vertical dotted line represents the year for which the inputs and

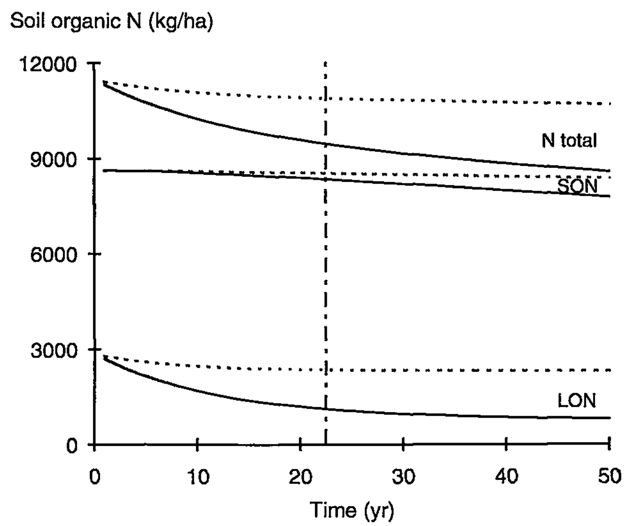

Figure 4.3 Changes in LON, SON and total soil N over a 50 year period for the reference maize production technique without organic amendments (——) and for a similar technique, but with immediate incorporation of slurry (-----); the year used for calculations in the TCG (– · – · –).

outputs for maize have been calculated. By covering the N requirement of maize mainly by slurry, the size of the labile N pool after 20-25 years is about twice as large as with artificial fertilizer only. Annual mineralization rates are 175 and 85 kg N ha^{-1}, respectively. Both, total N from slurry and from mineralization are used less efficiently than from artificial fertilizer, resulting in higher N losses under slurry application (Table 4.5).

In general, the model results are in good agreement with independent experimental results:

- N uptake without fertilizer application, after 20-25 years of only inorganic N addition is 60 kg ha^{-1}. After 20-25 years of only slurry application, N uptake without fertilizer application is 100 kg N ha^{-1}. The former value is rather low, but the latter agrees with field measurements (Schröder & Ten Holte, 1992). In general, large amounts of manure have been applied to maize fields, so the organic N pool has built up considerably (Schröder & Dilz, 1987).

- On average, 35 % of the N accumulated in a catch crop is recovered in the subsequent maize crop (Schröder & Ten Holte, 1992). The transfer coefficient in the TCG for this transformation is 0.32 (Table 4.3). Part of the N added to the labile organic pool becomes available through mineralization during the course of the subsequent growing season. Considering the size of the organic N pool, it is almost impossible to experimentally assess, the increase in organic N due to cultivation of a catch crop. Hence, no data are available to validate the transfer coefficient used in the TCG.
- Schröder & Dilz (1987) reported a leaching loss under maize of 145 kg N ha^{-1} at an application rate of 260 kg slurry N and an N yield of 131 kg on a sandy soil. The model results, i.e. a leaching loss of 120 kg N at an application rate of 250 kg slurry N and an N yield of 140 kg, are in close agreement with these values.
- Schröder et al. (1992) reported an N uptake of 123 kg ha^{-1} and nitrate leaching losses of 58 kg N ha^{-1} at a side dressing of 20 kg N ha^{-1} and of 193 and 105 kg, respectively, at an application rate of 126 kg. In the TCG, 225 kg N fertilizer is required when broadcast for an N uptake of 185 kg ha^{-1} (Table 4.5). Calculated nitrate losses, including denitrification, are 130 kg N ha^{-1}.

The EU norm for drinking water is 11.3 mg nitrate-N l^{-1}. Assuming a rainfall surplus of 300 mm per year, contributing fully to ground-water recharge, this norm is equivalent to a nitrate leaching loss of 34 kg N ha^{-1}. Part of the nitrate that is not denitrified will leach during the winter period. It may be concluded from the results presented here that, under Dutch growing conditions on sandy soils, maize cannot be cultivated without taking measures to reduce nitrate loss, if the EU norm for drinking water is to be met on an individual field basis.
This analysis confirms the poor image of maize with respect to nitrate leaching. However, it should be noted that the experimental data for maize, especially the N recovery, show a wide variation, that cannot simply be explained by environmental conditions or management practices. In some experiments, N recoveries of 75 to 90 % have been achieved (Spiertz & Sibma, 1986; Van der Meer & Wedin, 1989). This needs further research.
The model may also be applied to other target N concentrations, by defining alternative target fertilizer rates or yields. Such applications, however, fall outside the scope of this study.

4.5.2. Fodder beet production techniques

For fodder beets, the effects of the various measures are similar to those for the maize production techniques, although the magnitude differs considerably as a result of its longer growing season and its higher apparent N recovery. Fodder beets take up a large part of the available N and the amount left in the soil in autumn is rather small, as shown in various trials, i.e. 19-45 kg ha^{-1} at N application rates of about 150 to 200 kg ha^{-1} (Prins et al., 1988; Ten Holte & Van Keulen, 1989; Neeteson & Ehlert, 1989; Geelen, 1992; Aarts, in prep). Nitrate losses were appreciable, but only at high application rates.

The fertilizer requirements for the subsequent maize crop are 45 kg lower if the leaves are left in the field. The Dutch Extension Service advises reducing N application by 25 kg for the subsequent crop, so the TCG assumes better utilization of N incorporated in leaves. However, the organic N pool has also built up during the 20-25 years that beet leaves have been left in the field, resulting in a 25 kg higher N uptake without fertilizer application. It is assumed that 10 % of the N in the leaves is lost. Ten Holte (in press) reports that the amount of N in the upper 10 cm of the soil increased slightly when the leaves were left in the field. However, this is far less than the amount contained in the leaves. The fate of the remainder of the leaf N is unclear, except that no nitrate was leached to deeper soil layers. Debruck (1979) reported that 25-40 % of the N in beet leaves ploughed in, was taken up by the three subsequent crops, 10-15 % was lost by leaching and about 50 % was present as organic N in the soil after 3 years. These observations indicate a considerable degree of immobilization of N in the stable or labile organic N pool.

4.5.3. Evaluation of the TCG for maize and fodder beet

The major components of the TCG models for maize and fodder beet are formed by the relationship between N uptake and crop production and the mass balance model for N in the soil. The accuracy of these relations and their parameters directly affect the accuracy of the generated technical coefficients. For P, only an input/output balance, based on the standard P concentration in the products, is calculated. Interactions between N and P have not been considered due to lack of information.

The relationship between N uptake and crop production is based on experimental data for sandy soils, averaged over several years and locations. Other relationships or parameter values will yield slightly different technical coefficients. If the model is to be used for a specific site, a relation based on experiments for that site should be used. If experimental data are not available, the average for sandy soils presented here would be most appropriate.

The other important TCG component is the N mass balance model (Wolf et al., 1989). This model was selected for several reasons. It is a simple and well-documented N mass balance model, which has been tested for various situations. The number of parameters required is relatively low and most of them can be derived from field experiments and the literature. More detailed models require much more information and still have difficulties in simulating N fluxes in the soil (Van Keulen & Seligman, 1987), they have not been tested yet (Verberne, 1992) or are still under development (Whitmore & Schröder, in prep.). The results of the N balance model in this study agree reasonably well with experimental results. Wolf & Van Keulen (1989) also found a satisfactory agreement between model results and the results of three long-term field experiments but each experiment requires calibration, i.e. parameter adjustment. However, Whitmore & Schröder (in prep.) had problems matching the mineralization rate to the measured values of N uptake in the absence of fertilizer application and soil N accumulation. In this study, the calculated changes in the organic N pool could not be verified. Hence, some doubts about the general applicability of the model remain.

Application of the model requires quantification of the transfer coefficients, the size of the organic N pool in the soil partitioned between labile and stable organic N and their turn over rates. As the amount of N in LON and SON is very large, compared with N-fluxes in the system, the LON turn-over rate influences the technical coefficients more than the transfer coefficients of other sources of N. The turn over rates of LON and SON have been assumed to be constant. However, when changing agricultural practices and crops, the quality of organic amendments to the soil may change the turn over rates of soil organic matter. Small changes in turn over rate may considerably influence the amount becoming available via mineralization, as the organic pools contain large amounts of N. For instance, at a LON of 2000 kg N and a turn over rate of 13 years, 155 kg N mineralizes annually. At turn-over rates of 10 and 15 years, 200 kg and 130 kg N mineralizes annually. For maize in particular, a large part of the N mineralized is not available to the crop. Hence, the turn over rate has a considerable influence on nitrate losses.

The initial size of the organic N pool, the mineralization rate and the length of the period after breaking up grassland all affect the calculated technical coefficients. More fertilizer has to be applied to reach production targets if the initial size of the organic N pool is smaller. N uptake from both organic and inorganic fertilizer is higher and N losses are lower than from LON. Hence, on soils with a small labile organic N pool, nitrate losses are lower than on soils with a large labile organic N pool, provided the same production target can be achieved. After breaking up grassland and starting arable cropping a new equilibrium between LON and SON will establish itself. Taking into account the time constants for conversion of the labile and stable pools, 13 and 260 years, respectively, it may take centuries before a new equilibrium is reached, especially if the gap between the initial and the final equilibrium is large. Hence, in practice, a new equilibrium is never reached, because agricultural practice is never constant over such a long period. It is also questionable wether the initial situation under permanent grassland was in equilibrium, i.e. LON:SON was 1:3. However, the major changes in the labile pool occur during the first 20 years (Figure 4.3) and the influence of the size of the SON is limited within such a period.

5. Structure of the optimization matrix for integrated dairy farming

The optimization model for integrated dairy farming is formulated as a multiple goal linear programming (IMGLP) matrix. The rows are linear relationships describing the goals and constraints of the system, and the columns represent the activities. The relevant rows and columns are linked by technical coefficients. Table 5.1 gives an overview of the matrix. For clarity, the coefficients are represented by a '+' or a '-', rather than their actual values. A '+' indicates an input to the relevant activity and a '-' an output from that activity. The unit of each coefficient follows from the matrix by taking the unit of the row per unit of the column. A '+1' or a '-1' indicates that the unit of the row equals the unit of the column: the coefficient is then unity and unitless.
The technical coefficients of the land-use activities were quantified by the TCG models for various crops (Chapters 2, 3 and 4). They are expressed per ha of land for a wide range of crop production techniques. In the grass production and utilization techniques, the cattle summer ration is included, as explained in Chapter 2. The values of additional technical coefficients are given in Appendix B.

5.1. Goals

The goals considered in this study are based on the information given in Chapter 1. They relate to:

- nitrate leaching (minimized)
- ammonia volatilization (minimized)
- N surplus on the mineral balance (minimized)
- P surplus on the mineral balance (minimized)
- milk production (maximized)
- income (maximized)
- labour input (minimized and maximized)
- landscape (maximized)

The N and P surpluses on the mineral balance are defined as the difference between the inputs and outputs of the dairy farming system. Inputs are deposition, fertilizer and supplements and outputs are milk and meat. N surplus covers nitrate leaching, ammonia volatilization, denitrification and accumulation. P surplus covers accumulation and 'unavoidable' losses. The magnitude of the latter is still a matter of discussion and research. Milk production is a combined result of stocking rate and production level per cow.

Labour income is defined as the difference between financial returns and non-factor costs, capital costs and land rent. It covers the remuneration for the use of the production factor labour, increased by some farm-specific costs that were not taken into account in the model, such as 'polder taxes'. The net result is defined as labour income minus a remuneration for labour at parity wages. Hence, it is a form of remuneration for entrepreneurship and management. Labour input is both maximized and minimized to explore the limits of employment. Labour requirements are based on normative 'task times' (Pelser, 1988). Landscape development is defined by allocating a variable part of the available area to wooded banks and by imposing a minimum on the number of dairy cows kept outside in summer.

5.2. Activities

The activities are classified in land-use activities, feeding activities, cattle production activities, activities describing the N flows via slurry to crops and losses and purchase and sale activities. Most activities listed in the top row of Table 5.1 are further divided into sub-activities, as indicated by the relevant indices. For instance, the second activity XF(), the set of production techniques for conserved herbage, is subdivided by four values of F into the techniques: making hay, silage cut at 4000 kg DM ha^{-1}, silage cut at 3000 kg DM ha^{-1} and artificially dried grass. For eight values of N XF() is subdivided into eight N application levels. Hence, 4x8 = 32 techniques for the production of conserved herbage have been formulated. The meaning of the indices and acronyms is given in Appendix A.

The land-use activities have been discussed in detail in the preceding chapters. An additional land-use activity is the area under wooded banks.

The transfer of crop products to cattle is regulated via feeding activities, except for fresh herbage, which is taken into account under grass production and utilization techniques. Feeding activities are expressed in kg dry matter of the relevant product.

The cattle production activities quantify inputs and outputs per animal and are linked to the grass production systems via the stocking rate. The inputs refer to the cattle feed ration in winter, expressed in energy, protein and phosphorus requirements. The outputs refer to the production of milk and meat .

A separate set of activities is defined describing the N flows via slurry and to crops. The part of the nitrogen consumed that is not incorporated in products is collected in slurry. Subsequently, N losses by volatilization occur from stable and storage, and during and after slurry application. Part of the N applied with organic and inorganic fertilizers is not taken up by the crop, but denitrifies or leaches to the ground-water. These activities are expressed in kg N.

The purchase activities refer to concentrates and inorganic fertilizers. Seed, pesticides, straw, veterinary costs, etc. are specified as variable costs for each crop or animal category in Dutch florins (Dfl) per ha. Purchase of machinery and buildings is taken care of by fixed costs (Section 5.3). Furthermore, contract labour is hired for slurry application, cultivation of maize and fodder beet and ensiling grass. The sale activities refer to milk and meat. Both, purchase and sale activities are expressed in kg of the relevant product.

5.3. Constraints

The constraints are classified in a similar way as the activities. The numbers in the text refer to the constraint numbers in Table 5.1. The first group of constraints (1 to 7) refers to land use, stocking rate and animal products; the second group (8 to 11) links the feeding activities to crop production; the third group (12 to 20) describes the energy and protein supply to the cattle; the fourth group (21 to 40) describes the N flows via slurry to crop products and losses and in the fifth group (41 to 49) the purchase constraints have been formulated. The last constraint (50) is a N balance row. The constraints are discussed in more detail on the basis of Table 5.1.

The area occupied by the land-use activities must be equal to the total area available. In all cropping activities land can be reserved for wooded banks. Summation gives the total area under wooded banks (2). With a constant number of cattle a grassland area cannot be grazed throughout the whole season (Chapter 2). Therefore, part of the area has to be cut for conservation. In the model this is formulated as a minimum area to be cut for each ha grazed or used for zero-grazing (3). The N application rate has to be the same for the cut and the grazed area. Hence, this row applies to each N application level. The total number of animals is calculated from the grass production systems (4). Grass is the basic component of the ration in summer. Hence, the grass production systems determine the stocking rate for all animal categories (Chapter 2). The ratio between the number of calves and yearlings and the number of dairy cows is constant, as the replacement and birth rates are constant (5). Milk production is summed over all dairy cows (6). Meat production includes culled young animals, animals fallen out and replaced dairy cows (7).

Forage cannot be purchased or sold, to prevent shifting of the associated N and P losses. Concentrates originate from by-products of arable farming or are

Table 5.1 Schematic presentation of the IMGLP-matrix.

	index	code	unit	Land use activities						Feeding activities				
				XAREA	XG Y,B,N C,M	XF F,N	XM S,N,A R,W,Q	XB S,N,A,R L,W,Q	XLSL	XFV F,N,Y M,Z	XMV Q,P,S Y,M,Z	XBVB S,Y M,Z	XBVL S,Y M,Z	XC T,P,Y M,Z
				ha	ha	ha	ha	ha	ha	kg	kg	kg	kg	kg
1	NO3 loss		kg N											
2	NH3 loss		kg N											
3	N-surplus (balance)		kg N		+	+	+	+	+					
4	P-surplus (balance)		kg P		+	+	+	+	+					
5	milk production		kg											
6	labour income		Dfl											
7	labour		hour											
8	wooded banks		ha						+1					
9	cows outside		head		+									
10	net result		Dfl											
	CONSTRAINTS													
1	area		ha	-1	+1	+1	+1	+1	+1					
2	landscape		ha		-	-	-	-	+1					
3	ratio XF/XG	N	ha		+	-1								
4	number of cattle	Y,B,N,C,M,Z	head		+									
5	young stock/cow	Y,Z	-											
6	milk production		kg											
7	animals sold	Y	head											
8	prod. cons. grass	F,N	kg			-				+				
9	production maize	Q,S	kg				-	-			+			
10	prod. fodder beet	S	kg					-				+		
11	prod. beet leaves	S	kg					-					+	
12	maize, summer	Y,P,Q	kg		+						-1			
13	conc., summer	Y,M,T,P,Q,Z	kg		+						-1			-1
14	energy, winter	P,Y,M,Z	MJ							-	-	-	-	-
15	dve, winter	P,Y,M,Z	kg							-	-	-	-	-
16	oeb balance	P,Y,M,Z	kg							-	-	-	-	-
17	conc. intake, winter	P,Y,M,Z	kg							-	-	-	-	-
18	replacement forage	F,Q,P,Y,M,Z	kg							-1	-1			
19	dm intake	P,Y,M,Z	kg							+1	+1	+1	+1	+1
20	limit intake struc.	P,Y,M,Z	-							+	+		+	
21	N intake, winter	P,Y,M,Z	kg N							-	-	-	-	-
22	P intake, winter	P,Y,M,Z	kg P							-	-	-	-	-
23	N feeding losses		kg N							-	-	-	-	-
24	N slurry	Y,M,	kg N		-									
25	NH3 vol. storage	P,Z	kg N											
26	N available slurry		kg N											
27	N applied slurry		kg N											
28	N supply to XG()		kg N		+									
29	N supply to XF()		kg N			+								
30	limit injection grass	G	kg N		+	+								
31	max. slurry appl.	G	kg		+									
32	organic N balance XG()		kg N		+									
33	organic N balance XF()		kg N			+								
34	fertilizer N XM()		kg N				+							
35	slurry N XM()	A	kg N				+							
36	fertilizer N XB()		kg N					+						
37	slurry N XB()	A	kg N					+						
38	NO3 loss		kg N		-	-	-	-	-					
39	NH3 loss		kg N		-	-								
40	N2O losses		kg N		-	-	-	-	-					
41	P/K supply to XG()		kg P/K		+									
42	P/K supply to XF()		kg P/K			+								
43	P/K supply to XM()		kg P/K				+							
44	P/K supply to XB()		kg P/K					+						
45	conc. purchase	T	kg											+1
46	variable costs		Dfl		+	+	+	+						
47	costs contract labour		Dfl		+	+	+	+						
48	fixed costs		Dfl	+	+	+				+	+	+	+	
49	labour input		hour		+	+				+	+	+	+	
50	N balance row		kg		+	+	+/-	+/-	+/-					

continued on next page

		Cattle activities			Activities describing the N flow via slurry to crops and losses											
XCONC	XDMIW		XYS		XNSL		XFLN	XNH3S	XNAVS	XSLA	XNBLG	XNBLF	XNO3T	XNH3T	XN2OT	XNSUM
Y,M,Z	Y,M,Z		Y,B,N,C,M,Z		Y,M,P,Z			Y,P,Z		A,G						
		Y1		Y2,3	P1	P2										
kg	kg dm		head		kg N		kg N	kg N	kg N	kg N	kg N	kg N	kg N	kg N	kg N	kg N
													+ 1			
														+ 1		
										+						
										+						
			-													
		+ 1		-												
		-														
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															+ 1	
										-						
										-						
			+													
										+						
			+													
		+		+						+						
			-								- 1	- 1	- 1	- 1	- 1	- 1

Table 5.1 continued

			Purchase activities								Sale activities		RHS	
		code index unit	XCT T kg	XNFER G kg N	XPFER G kg P	XKFER G kg K	XVARC Dfl	XCCL Dfl	XFIXC Dfl	XLAB hour	XSALE Y head	XMILK kg	type	
1	NO3 loss	kg N												
2	NH3 loss	kg N												
3	N-surplus (balance)	kg N	+	+							-	-		
4	P-surplus (balance)	kg P	+		+						-	-		
5	milk production	kg										+ 1		
6	labour income	Dfl	+	+	+	+	+ 1	+ 1	+ 1		-	-		
7	labour	hour								+ 1				
8	wooded banks	ha												
9	cows outside	head												
10	net result	Dfl	+	+			+ 1	+ 1	+ 1		-	-		
	CONSTRAINTS													
1	area	ha											EQ	0
2	landscape	ha											EQ	0
3	ratio XF/XG	ha											LE	0
4	number of cattle	head											EQ	0
5	young stock/cow	-											EQ	0
6	milk production	kg										+ 1	EQ	0
7	animals sold	head									+ 1		EQ	0
8	prod. cons. grass	kg											LE	0
9	production maize	kg											LE	0
10	prod. fodder beet	kg											LE	0
11	prod. beet leaves	kg											LE	0
12	maize, summer	kg											EQ	0
13	conc., summer	kg											EQ	0
14	energy, winter	MJ											EQ	0
15	dve, winter	kg											LE	0
16	oeb balance	kg											LE	0
17	conc. intake, winter	kg											EQ	0
18	replacement forage	kg											GE	0
19	dm intake	kg											EQ	0
20	limit intake struc. mat.	-											GE	0
21	N intake, winter	kg N											EQ	0
22	P intake, winter	kg P											LE	0
23	N feeding losses	kg N											EQ	0
24	N slurry	kg N											EQ	0
25	NH3 vol. storage	kg N											EQ	0
26	N available slurry	kg N											EQ	0
27	N applied slurry	kg N											EQ	0
28	N supply to XG()	kg N		- 1									EQ	0
29	N supply to XF()	kg N		- 1									EQ	0
30	limit injection grass	kg N											GE	0
31	max. slurry appl.	kg											GE	0
32	organic N balance XG()	kg N											EQ	0
33	organic N balance XF()	kg N											EQ	0
34	fertilizer N XM()	kg N		- 1									EQ	0
35	slurry N XM()	kg N											EQ	0
36	fertilizer N XB()	kg N		- 1									EQ	0
37	slurry N XB()	kg N											EQ	0
38	NO3 loss	kg N											EQ	0
39	NH3 loss	kg N											EQ	0
40	N2O losses	kg N											EQ	0
41	P/K supply to XG()	kg P/K			- 1	- 1							LE	0
42	P/K supply to XF()	kg P/K			- 1	- 1							LE	0
43	P/K supply to XM()	kg P/K			- 1	- 1							EQ	0
44	P/K supply to XB()	kg P/K			- 1	- 1							EQ	0
45	conc. purchase	kg	- 1										EQ	0
46	variable costs	Dfl					- 1						EQ	0
47	costs contract labour	Dfl						- 1					EQ	0
48	fixed costs	Dfl	+						- 1				EQ	0
49	labour input	hour	+							- 1				
50	N balance row	kg	+	+ 1							-	-	EQ	0

imported into the region. In fact, the area used outside the region to produce concentrates should also be taken into account. However, this goes beyond the scope of this study.
Products from the cropping techniques are transferred to the feeding activities. The maximum amount of conserved grass available is the amount produced by the techniques XF() (8). The maximum amount of maize available is the amount produced by continuous maize cultivation (XM()) and by rotation with fodder beet (XB()) (9). The maximum amount of fodder beet and beet leaves available is the amount produced by the activities XB() (10, 11). As the IMGLP model refers to an average year, no forage can be reserved for the subsequent year, nor are reserves available from previous years.
In summer, some zero-grazing and all day grazing systems require 4.5 kg maize per cow per day (12). If the available grass and maize cannot meet the feed requirements of the animals in summer, the feed has to be supplemented with concentrates. Ground ear silage can be produced in the region itself, other concentrates used in summer have to be purchased (13).
In winter, conserved grass, maize, fodder beet, fodder beet leaves and purchased concentrates can be fed. The ration is composed in such a way that the energy requirements are just met by the supply (14). The DVE supply at least covers the requirements (15). The OEB is calculated, but is not constraining (16).
Concentrates replace part of the roughage. Artificially dried grass, ground ear silage, fodder beet roots and beet leaves are considered concentrates. Combined with purchased concentrates they partly replace forage (hay, grass silage and maize silage; 17, 18). Hence, the maximum roughage intake is reduced. Total dry matter intake is limited physiologically depending on the milk production per cow (19). Part of the diet should consist of fibrous material to prevent digestion problems. The contribution of a feed to fibrous material is expressed as a structure value. The structure value of the ration should be at least 0.33 (20).
Total N and P intake by cattle in winter is divided into products and slurry (21, 22). Milk and meat have a constant P and N content and the remainder is added to slurry. The amount of N collected in slurry in summer is calculated in GRASMOD. Feeding losses in the stable are added to slurry (23, 24). Part of the N present in slurry volatilizes (25). The remaining nitrogen is available for application in various ways and to all crops (26, 27). All slurry has to be applied within the region.
The N requirements of the grass production and utilization techniques can be met by any combination of slurry and inorganic fertilizer (28, 29). However, slurry can only be injected once a year in spring to prevent sod damage (30). Total slurry application on grazed grass is limited to a maximum to prevent

hypomagnesemia in dairy cows (31). The organic N balance of grassland is calculated by adding the organic N applied with slurry to the N balance calculated in GRASMOD (32, 33). For maize and fodder beet the required amounts of inorganic N fertilizer and slurry, as calculated in the TCG models, have to be met (34 - 37).

Nitrate leaching originates from land-use activities. On well-drained sandy soil about 10 % of the N lost from the rooted zone denitrifies and 90 % is lost by leaching, (Steenvoorden, 1988; Boumans et al., 1989) (38, 40). Ammonia volatilization comes from urine and faeces during grazing, decaying plant material, slurry application, housing and slurry storage (39).

In addition to P and K applied with slurry, P and K fertilizers can be purchased if necessary (41-44). The total amount of concentrates to be purchased is calculated (45). Total non-factor costs or variable costs are the expenses on items whose availability and application are variable, including contract labour (46, 47). Here, variable costs and the cost of hiring contract labour are kept separate. Fixed costs (48) include the costs of machinery and buildings. On a commercial farm a farmer decides whether to buy machinery or not. This may result in slack equipment, if it cannot be fully utilized, increasing the cost per hour usage. As some cropping activities, adapted to ensure minimal environmental losses require specific machinery, the capital costs also have to be considered. This would require identifying various sets of available machinery and scale effects would be introduced. To avoid this, the cost of machinery required for the cultivation of fodder crops is based on the concept of reimbursement by mutual usage (National Reference Centre for Agriculture, 1993) and assigned to the cropping area according to its use. This reimbursement includes depreciation, maintenance and insurance, cost of parking, additional costs and risk, and interest. The costs are defined as a percentage of the replacement value of the machines (National Reference Centre for Agriculture, 1993). The same applies to milking equipment, the only difference being that these costs are assigned to the dairy cows. The annual cost of buildings, as a percentage of the replacement value, covers depreciation, maintenance, insurance and interest. These costs are assigned to the dairy cows. The size of milking equipment and buildings is based on a rather large herd of 100 dairy cows, implying that the fixed costs per cow are low compared to those of smaller herds. Hence, all fixed costs have been converted to variable costs and are either assigned to land or to animals. Farm labour input (49) in expressed in hours.

The last row (50) contains the N balance of the dairy farming system selected. All N inputs and outputs are added. This provides a check on the calculated N flows. The balance should be close to zero.

6. Optimization results of various scenarios for dairy farming on sandy soils

In this chapter, first the solution area as determined by the goals nitrate leaching, ammonia volatilization and labour income will be described, and optimization results for dairy farming with no restrictions will be given (Section 6.1). This is followed by optimization results for two scenarios in dairy farming. The first scenario represents dairy farming according to the nitrogen policy objectives as laid down by the government for the year 2000 (Section 6.2). It concentrates on the goals nitrate leaching, ammonia volatilization and labour income on a regional scale with no restrictions on other goal variables. In the second scenario the other goals defined in preceding chapters are optimized (Section 6.3). Their optimum values, the trade-offs between various goals when restrictions are imposed, and the associated dairy farming systems are discussed. All the results presented in this chapter pertain to an average ha in the region.

6.1. Nitrogen losses and labour income on a regional scale

6.1.1. The solution area as determined by regional nitrogen losses and labour income

In the first iteration each of the goals nitrate leaching, ammonia volatilization and labour income are optimized individually without imposing restrictions on any of the other goals. This results in the best attainable value for each goal under the defined conditions (Table 6.1).

Minimum nitrate leaching is 14 kg N. Minimum ammonia volatilization in this situation is 0, but this is associated with a large negative labour income, i.e. Dfl -4 255 (optimization 1). Maximum labour income at a nitrate leaching of 14 kg is Dfl 3 440, but then an ammonia volatilization of 128 kg N has to be accepted (optimization 2). Hence, at the minimum leaching loss a wide range of values for ammonia volatilization (0 to 128 kg N) and labour income (Dfl -4 255 to 3 440) is possible, but by setting either one to a certain value, the other value is also fixed.

Ammonia volatilization can be reduced to 0. Minimum nitrate leaching is then 14 kg N and the associated labour income is Dfl -4 255 (optimization 3). The results of optimization 3 are identical to those of 1. Maximum labour income without any volatilization, is only Dfl -3 420 with an associated nitrate loss of 78 kg N (optimization 4). In this case, the possible range in labour income is only Dfl 835, but the range in nitrate leaching, i.e. 14 - 78 kg N, is considerable. If no

Table 6.1 Extreme values of three goals optimized (**bold**) and the associated values of the other goal variables;( ) minimization or maximization of the goal variable.

Goal variable	Optimization no.		NO_3 leaching	NH_3 volatilization	Labour income
			kg N ha^{-1}	kg N ha^{-1}	Dfl ha^{-1}
NO_3 leaching	1	min. NH_3 volatilization	**14**	0	-4 255
(minimize)	2	max. labour income	**14**	128	3 440
NH_3 volatilization	3	min. NO_3 leaching	14	**0**	-4 255
(minimize)	4	max. labour income	78	**0**	-3 420
Labour income	5	min. NO_3 leaching	56	178	**5 250**
(maximize)					

volatilization is permitted at all, no animals can be kept. Hence, the systems selected in optimizations 1 and 3 cover crops only. The area assigned to landscape purposes is at its maximum value of 5 %. Labour income is negative, because all land has to be used, but the fodder produced cannot be sold, and accumulates or is transported outside the region without giving any return. The results of these optimizations are correct in model terms but, of course, not very realistic.

Maximum labour income, with no goal restrictions is Dfl 5 250. The associated nitrate and ammonia losses are 56 and 178 kg N, respectively, and no variation is possible (optimization 5). Hence, the highest leaching and volatilization losses in these optimizations are 78 and 178 kg N, respectively.

The results in Table 6.1 define the outer boundaries of the solution area. In subsequent iterations, the solution area has been established by tightening the goal restrictions for leaching and volatilization step-by-step, while maximizing labour income. The restriction on nitrate leaching has been reduced from 79 to 14 kg N in steps of 5 units and on ammonia volatilization from 180 to 50 kg N in steps of 10 units and below 50 kg N in steps of 5 units, as the latter is the more interesting range.

The results are given in Figure 6.1, where ammonia volatilization and nitrate leaching levels are connected by iso-labour income lines. The numbers 1-5 in this figure correspond with the optimization numbers in Table 6.1. At the minimum leaching loss of 14 kg N, the possible variation in volatilization and labour income is indicated. The possible variation in nitrate leaching in the absence of volatilization is indicated on the x-axis. As this is a single line, the associated

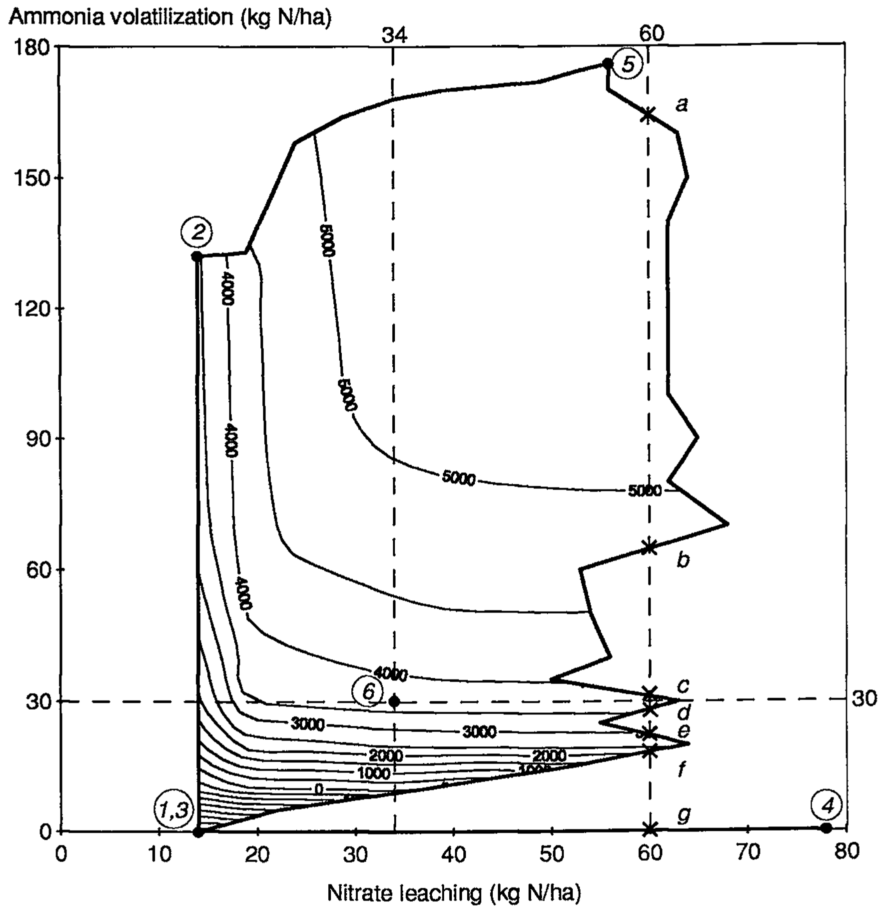

Figure 6.1 The solution area for dairy farming as defined by optimization of nitrate leaching, ammonia volatilization, and labour income (Dfl ha^{-1}) on a regional scale. Labelled lines: iso-labour income lines; numbers 1-6 refer to optimizations as explained in the text.

labour income cannot be read from the figure. Point 5 represents the maximum labour income. No variation in leaching and volatilization losses is possible without decreasing labour income or accepting unnecessary losses.
The denser the iso-labour income lines become (Figure 6.1), the higher the costs of emission reduction per kg N. It makes no difference to the solution area which of the goals is optimized and which are restricted. At each point in the

solution area the combined values of the goal variables represent the optimum combination. The value of none of the goal variables can be improved without altering one of the others and thus without moving to another point. For points outside the solution area, neither leaching nor volatilization losses limit labour income, hence either or both their values can be reduced until the edge of the hatched area is reached without reducing labour income. This is illustrated by means of an example.

When nitrate leaching is restricted to 60 kg N, the maximum ammonia volatilization necessary to reach the highest attainable labour income is 163 kg N (a). At this point N losses by volatilization are 15 kg lower and by leaching 4 kg higher than under optimization 5. Labour income is reduced by only Dfl 2 to Dfl 5 248. Hence, leaching and volatilization are, to some extent, interchangeable. Tightening the restriction on ammonia volatilization to 65 kg N decreases labour income to Dfl 4 750 (b). A further tightening towards 32 kg N ha^{-1} (c) leads to points outside the solution area. Hence, the restriction on leaching of 60 kg N does not limit labour income in the range between 65 and 32 kg N volatilization. The restriction on leaching can be tightened until the edge of the solution area is reached (c). For instance, at a volatilization rate of 35 kg N, nitrate leaching can be reduced from 60 to 50 kg N without loss of labour income. By further tightening ammonia volatilization to below 32 kg, both leaching and volatilization have a restrictive effect on labour income. At a volatilization rate of 22 - 28 kg N (e-d) and below 18 kg N (f-g), leaching is again not limiting on labour income. If no volatilization is permitted, leaching limits labour income. However, this is again an unrealistic situation excluding animals from the system.

A similar analysis can be made along the horizontal lines in Figure 6.1 which show a constant volatilization rate and increasingly tighter restrictions on leaching. By tightening the three goal restrictions in turn, an indented line through the solution area is produced.

Figure 6.1 shows that a reduction in nitrate leaching to about 35 kg N hardly affects labour income. At leaching losses below 35 kg the reduction in labour income depends on the permitted volatilization rate. The same applies to volatilization to a rate of about 100 kg N. The marginal decrease in labour income increases with increasingly tighter restrictions on N losses. The marginal decrease in labour income due to a reduction in ammonia volatilization is higher than due to a reduction in nitrate leaching.

Each point in the solution area in Figure 6.1 is characterized by a distinct set of production systems for grass, maize, fodder beet and cattle, which together describe the regional dairy farming system. In the following section, the points 5 and 2, representing maximum labour income and minimum nitrate leaching without restrictions on other goals, are analysed in more detail. Actually, over the whole line between points 1 and 2, leaching is at its minimum value, but the production systems will be analysed for the point on this line representing the highest attainable labour income. Doing this for points 1, 3 or 4 would be futile, as a system at minimum ammonia volatilization is unrealistic. However, the influence of measures to reduce volatilization losses will be briefly discussed (Subsection 6.1.4).

6.1.2. Dairy farming when maximizing labour income without restrictions on other goals

Maximizing labour income implies aiming at a high milk yield per unit area and hence, a high crop production at low costs combined with high concentrate purchases. The results for optimization of labour income without restrictions are presented in Table 6.2. Under the conditions and price ratios as defined in Chapter 5, maximum attainable labour income is Dfl 5 250. This labour income is associated with leaching losses of at least 56 kg N and volatilization losses of at least 178 kg N. All land is used for grass production, about a third of which is conserved as silage. Grass for silage is cut at a yield of 4 t ha^{-1}, resulting in a high annual yield (Chapters 2 and 3). In winter, the energy demand of the cattle can be met by supplementation with purchased concentrates. Both, dairy cows and young stock are kept indoors all year-round. In summer, no additional maize is supplied. Zero-grazing is a more expensive system than the grazing systems considered, but grass yields are higher and the energy requirements of animals kept indoors are lower than those of grazing animals (Chapters 2 and 3). Hence, under a zero-grazing system a higher milk yield per ha can be achieved than under a grazing system. Apparently, the higher costs for zero-grazing are offset by higher production. Herbage feeding level is 80 % of the maximum, resulting in the highest possible stocking rate. Grass for conservation receives a higher N application than grass for summer feeding. On average, the annual application rate of inorganic N is 420 kg ha^{-1} grassland, of which 240 kg is purchased as artificial fertilizer and the remainder is applied in slurry. The total amount of N in slurry is 450 kg. At the standard N concentration of 4.4 kg m^{-3}, slurry production is 102 m^3 ha^{-1}, of which 34 m^3 is injected and 68 m^3 is applied by surface application. The stocking rate is 3.29 cows with their associated young. Milk production is 26 300 kg ha^{-1}. Labour inputs amount to 122 h ha^{-1}. Concentrate purchases are 13 130 kg ha^{-1} or 3 990 kg per cow per year. About 87 % of the purchased concentrates is ground ear silage (14.7 g N kg^{-1} DM) due

Table 6.2 Optimization results for maximum labour income and minimum nitrate leaching with no restrictions, in units per ha in the region. All figures pertain to an average ha in the region, except N application rate, which pertains to one ha grassland.

Characteristics production system	Unit	Maximum labour income	Minimum nitrate leaching
Goal			
Labour income	Dfl	5 250	3 440
NO_3-leaching	kg N	56	14
NH_3-volatilization	kg N	178	128
Land use			
Grass freshly fed			
Area	%	65	62
N application	kg	410	100
Grassland utilization			
cows		zero grazing - maize	zero grazing - maize
yearlings		zero grazing	zero grazing
calves		zero grazing	zero grazing
Herbage supply level		0.80	0.80
Grass conserved			
Area	%	35	33
N application	kg	440	100
Product		silage	silage
Landscape area	%	0	5
Slurry			
Total production	m^3	102	63
Grass, injection	m^3	34	7
Grass, surface application	m^3	68	56
Others			
Stocking rate	cows	3.29	2.47
Milk production	kg	26 300	19 770
Labour input	h	122	92
Concentrates	kg	13 130	10 260
N fertilizer	kg	240	0
N surplus	kg	395	170
P surplus	kg	29	31
Labour income per t milk	Dfl	200	174

to its relatively low price, 11 % is protein-rich (62 g N kg^{-1}), 1 % has an N content of 23 g kg^{-1} and 1 % of 20 g kg^{-1}. The N surplus is 395 kg ha^{-1}, of which 240 kg is lost by volatilization, leaching and denitrification, resulting in an N accumulation of 155 kg ha^{-1}. The P surplus is 29 kg ha^{-1}. All slurry can be applied, as the P surplus is not restricting. Labour income per tonne of milk produced is Dfl 200.

This dairy farming system is very intensive in terms of production per ha, and the associated N losses and N and P surpluses are high. It is selected, when regional labour income is to be maximized with no restrictions on emissions and milk production per ha. Taking into account that a year represents 2 237 working hours per labourer (National Reference Centre for Agriculture, 1993), 100 dairy cows would require 30.4 ha and 1.7 full time labourers. These results represent the most intensive system for the situation and the set of production techniques defined. If forage purchases and slurry sales were permitted, a more intensive feed lot system could be selected, depending on price ratios.

6.1.3. Dairy farming when minimizing nitrate leaching without restrictions on other goals

Minimizing nitrate leaching implies aiming for low N application rates and restricting grazing. The results for minimum leaching losses with no restrictions on other goals are shown in the right-hand column of Table 6.2. Minimum nitrate leaching is 14 kg N. Maximum attainable labour income is Dfl 3 440, i.e. 65 % of the absolute maximum, associated with an ammonia volatilization rate of 128 kg N.

All cultivated land is used for grass production, about a third of which is conserved as silage. Silage is cut at 4 t ha^{-1}, because of the high annual yield. The area used for landscape purposes is set to its maximum value of 5 %, as this is associated with the lowest leaching losses. Under continuous maize cultivation and in the maize/fodder beet rotation leaching losses are always higher than under grassland with low N rates. N application is 100 kg inorganic N ha^{-1}, both on grass fed freshly and on grass for conservation, i.e. the lowest value defined in the TCG, as nitrate leaching is directly related to N application rate (Chapters 2 and 3). Zero grazing systems are selected for all cattle types, because of the low leaching losses due to the absence of urine patches. Labour income is highest at a high milk production per ha, thus at a herbage supply level of 0.8. More slurry is produced than at a level of 1.0, but if it can be applied in the region and application of artificial fertilizer is reduced accordingly, there is no problem. In this case all N is applied as slurry. The amount of slurry produced is 63 m^3 ha^{-1}, of which 7 m^3 is injected and 56 m^3 is applied by surface application.

No N is applied in artificial fertilizer. Nitrate losses are not affected by slurry application method and surface application is cheapest. However, this is responsible for 58 % of the volatilization losses. Stocking rate is 2.47 cows plus associated young stock. Although nitrate losses are kept to the minimum, milk production at 19 770 kg is still high. Labour inputs are 92 h. Concentrate purchases are 10 260 kg ha^{-1} or 4 155 kg cow^{-1}, which is slightly higher than under optimization 5. About 28 % of the concentrates consists of ground ear silage (14.7 g N kg^{-1}), 47 % of the standard concentrate (23 g N kg^{-1}), 23 % is protein-rich (32 g N kg^{-1}) and 2 % is very protein-rich (62 g N kg^{-1}). N surplus is 170 kg, of which 145 kg is lost by volatilization, leaching and denitrification, resulting in an N accumulation of 25 kg. P surplus is 31 kg.

The main difference between this dairy farming system and the one described for maximizing labour income is N application rate, as land use and grazing systems are almost identical.

6.1.4. Strategies aimed at low ammonia volatilization

Measures to reduce ammonia volatilization involve the use of low-emission slurry application techniques, reducing N excretion and the construction of low-emission stables and slurry storages.

The influence of grazing is more complicated. Under grazing, volatilization depends on the amount of N excreted and the total N load in urine patches, including N applied in fertilizer (Chapters 2 and 3). Volatilization from stable and storage can be calculated from N excretion, the time period the animals are inside and type stable and slurry storage (Chapter 5). In all grassland utilization systems cows are inside at least part of the day during milking. Hence, total ammonia losses are a combination of volatilization inside and outside.

Figure 6.2 shows the influence of N application rate and grassland utilization method on total ammonia emissions in summer for standard stable and storage constructions and the application of slurry by shallow injection with open slits. Ammonia volatilization per cow is highest under day-and-night grazing, followed by zero grazing without maize supplementation (Figure 6.2a). In both systems the ration is based on grass only with a relatively high N content, resulting in a high level of N excretion. Supplementation with maize reduces ammonia volatilization. Under grazing, total volatilization losses are higher than under zero grazing due to the higher N-content in the grass. Losses from the stable are relatively high, as a smaller amount of N is present in slurry in the stable, but the emitting floor surface is equal to that under zero grazing. At higher application rates ammonia volatilization from the field also increases.

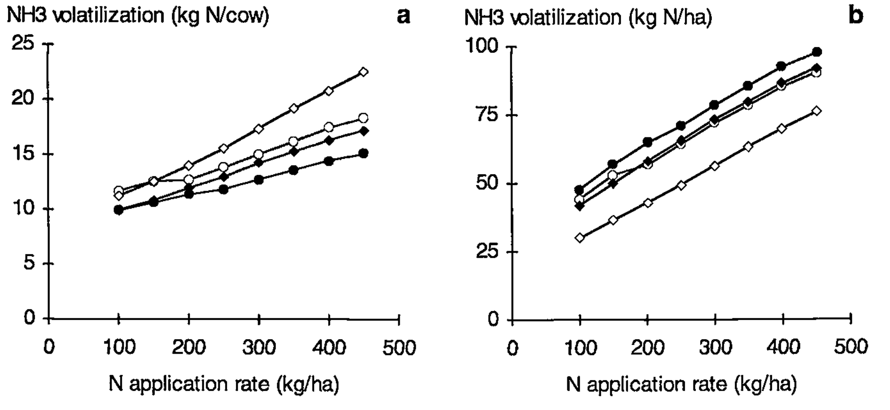

Figure 6.2 The relationship between N application rate and ammonia volatilization in summer (a) per cow and (b) per ha grassland for the various grassland utilization methods. –o– zero grazing - maize; –●– zero grazing + maize; –◇– day-and-night grazing - maize; –◆– day grazing + maize.

Under zero grazing without maize supplementation, standard concentrates are fed at N application rates of 100 and 150 kg. At an application rate of 200 kg, the N content in the grass is sufficient to introduce low-N concentrates into the ration. Hence, N excretion in slurry deceases and volatilization losses also. If the cows are supplemented with maize silage the introduction of low-N concentrates is more gradual and a smaller amount of concentrates is required, so the influence on N excretion is less distinct (Chapter 3). Figure 6.2a indicates that ammonia volatilization per cow and, at a similar production level, also per t milk, can be reduced by reducing the N application rate, reducing the N content of the ration by low-N feeds and by shifting to zero grazing.

If ammonia volatilization is expressed per ha grassland, day-and-night grazing is the most favourable system, followed by zero grazing without maize supplementation, day grazing and zero grazing with maize supplemention. However, both stocking rate and milk production also increase in this sequence. Figure 6.2b indicates that both reduction of N application and the introduction of day-and-night grazing reduce volatilization losses per ha.

In winter, volatilization is proportional to total N excretion and can only be influenced by the construction of low-emission stables and slurry storages. Volatilization per ha is influenced by N excretion per ha. Minimization of volatilization refers to volatilization in both winter and summer. The choice between the construction of a low-emission stable and storage, grassland utilization system and N application rate to reduce volatilization, will depend on the cost of construction and the reduction in revenues under grazing and at various N application rates.

Table 6.3 Optimization results for maximum labour income with restrictions of 34 kg N ha^{-1} on leaching and 30 kg N on volatilization; shadow price ( ). All figures pertain to an average ha in the region, except N application rate, which pertains to one ha grass or maize.

Characteristics production system		Unit	Results with restrictions
Goals			
Labour income		Dfl	3 810
NO_3 leaching		kg N	34 (4)
NH_3 volatilization		kg N	30 (57)
Land use			
Grass freshly fed			
Area		%	63
N application		kg	150
Grassland utilization	cows		day grazing+maize
	yearlings		day+night grazing
	calves		day+night grazing
Herbage supply level			1.0
Grass conserved			
Area		%	22
N application		kg	225
Product			silage, hay
Maize, continuous			
Area		%	15
N application		kg	150, injection, row
Winter crop			no
Product			silage
Slurry			
Total production		m^3	40
Grass, injection		m^3	13
Grass, sod fertilization		m^3	19
Maize, injection		m^3	8
Others			
Stocking rate		cows	2.05
Milk production		kg	16 350
Labour input		h	71
Concentrates		kg	5 470
N fertilizer		kg	75
N surplus		kg	140
P surplus		kg	8
Labour income per tonne milk		Dfl	233

6.2. Dairy farming in the year 2000

Dutch environmental policy aims to realize its objectives in several phases. By the end of the year 2000, ammonia volatilization has to be reduced by 50-70 % compared with that in 1980, which was about 100 kg N ha^{-1} (Min. of Housing, Spatial Planning and Environment, 1994; Lekkerkerk et al., 1995), and by 90% by the end of 2010. The EU nitrate norm for drinking water is 11.3 mg N l^{-1}, implying a nitrate leaching loss of 34 kg N ha^{-1} at an annual rainfall surplus of 300 mm, which has to be achieved by 2001. The EU indicates a value of 5.6 mg N l^{-1} or 17 kg N ha^{-1} in the long term (Min. of Housing, Spatial Planning and Environment, 1989).
The results analysed in this section apply to a situation in which there are restrictions on ammonia volatilization and nitrate leaching only. Hence, N surplus, P surplus and milk quota are not restrictive here.

6.2.1. Dairy farming according to government nitrogen policy objectives for the year 2000

At goal restrictions of 30 kg N ha^{-1} for ammonia volatilization and 34 kg N ha^{-1} for nitrate leaching, the maximum attainable labour income is Dfl 3 810 ha^{-1} (Figure 6.1, point 6), a reduction of 28 % compared with labour income in the absence of restrictions.
Table 6.3 gives the optimization results for government policy objectives in 2000. The shadow price of nitrate leaching is Dfl 4 kg^{-1} N, implying that relaxing the restriction on nitrate leaching by 1 unit increases regional labour income by Dfl 4 ha^{-1}. For ammonia volatilization, the shadow price is Dfl 57 kg^{-1} N. Hence, measures to reduce volatilization to its target value are more expensive per kg N than those to reduce leaching. Grassland occupies 85 % of the area, of which 22 % is used for conservation. Average inorganic N application to grassland is 170 kg, about 40 % of the rate in point 5 in Figure 6.1. In summer, dairy cows are outside during the day and inside at night, young stock is always outside. By reducing the N application rate by 60 %, the target nitrate leaching loss can still be achieved under grazing. Grass for conservation is cut at 4 t ha^{-1}. Part is conserved as silage and part as hay.
Maize is grown continuously. All the N required is applied by slurry injection in the row at a rate of 150 kg mineral N per ha maize. This is equivalent to 54 m^3 ha^{-1} and is permitted, as no limits on P have been defined so far. No winter crop is grown. Nitrate leaching under maize is 120 kg N. However, as only 15 % of the area is occupied by maize, this is compensated for by the low leaching losses under grassland. Hence, on a regional scale leaching losses do not exceed 34 kg N.

Total slurry production is 40 m^3, of which 13 m^3 is applied on grassland by deep injection and 19 m^3 by shallow injection and 8 m^3 on maize. The amount injected on grass is small, as slurry can only be injected once a year and N application rates are low. N supply to grassland is complemented by 75 kg artificial N fertilizer.

Low-emission stable and slurry storage constructions are used. Apparently all measures, i.e. reduced N application rate, low-emission stable and storage and low-emission slurry application techniques, are required to reduce volatilization to 30 kg N ha^{-1}.

The stocking rate is 2.05 dairy cows ha^{-1} with associated young stock. Milk production is 16.35 t ha^{-1}, i.e. 62 % of the production under maximum labour income without restrictions (Table 6.2). Concentrate purchases are 5 470 kg ha^{-1}, 3 130 kg of which is ground ear silage produced outside the region. Herbage supply level in summer is 1.0, resulting in lower concentrate purchases than at a herbage supply level of 0.8, as selected in optimizations 2 and 5. The cows' daily ration in winter consists of 9.9 kg concentrates, 4.2 kg grass silage, 1 kg hay and 0.6 kg maize silage. Hay has the highest structural value of the forages considered in this study, implying that the demand for fibrous material in the ration is met at a relatively low forage intake and concentrate input can be high to attain a high milk yield per ha. The DVE content of hay is higher than that of wilted silage, so less protein supplements are required and less is excreted in the urine and faeces. It depends on the quality and yield of other grass products, whether or not grass should be made into hay, as its yield is relatively low (Chapters 2 and 3). The N concentration in the ration is 24 g kg^{-1}. About half the amount of concentrate fed to dairy cows has a low N content (14.7 g kg^{-1}) and half is N-rich (32 g kg^{-1}). This ration meets precisely the cows' energy and DVE requirements. OEB is 180 g cow^{-1} d^{-1} during the winter period. The ration of the young stock in winter meets their energy requirements and has a total DVE surplus of 18 kg, due to the low N retention. The OEB value of the ration is 0.

The regional N surplus is 140 kg ha^{-1}, of which 64 kg is lost by leaching and volatilization, resulting in 76 kg N ha^{-1} that is not accounted for (denitrification and accumulation). P surplus is 8 kg ha^{-1}. Labour requirements are 71 h ha^{-1}, so 100 cows require 49 ha and 1.6 labourer.

Reducing N losses to the levels aimed at for the year 2000 leads to extensification of dairy farming, when compared to the optimization results obtained without any restrictions. Milk production is still rather high compared to commercial farms, but these are limited by milk quota, which have not been taken into account in the calculations. The main differences between this dairy

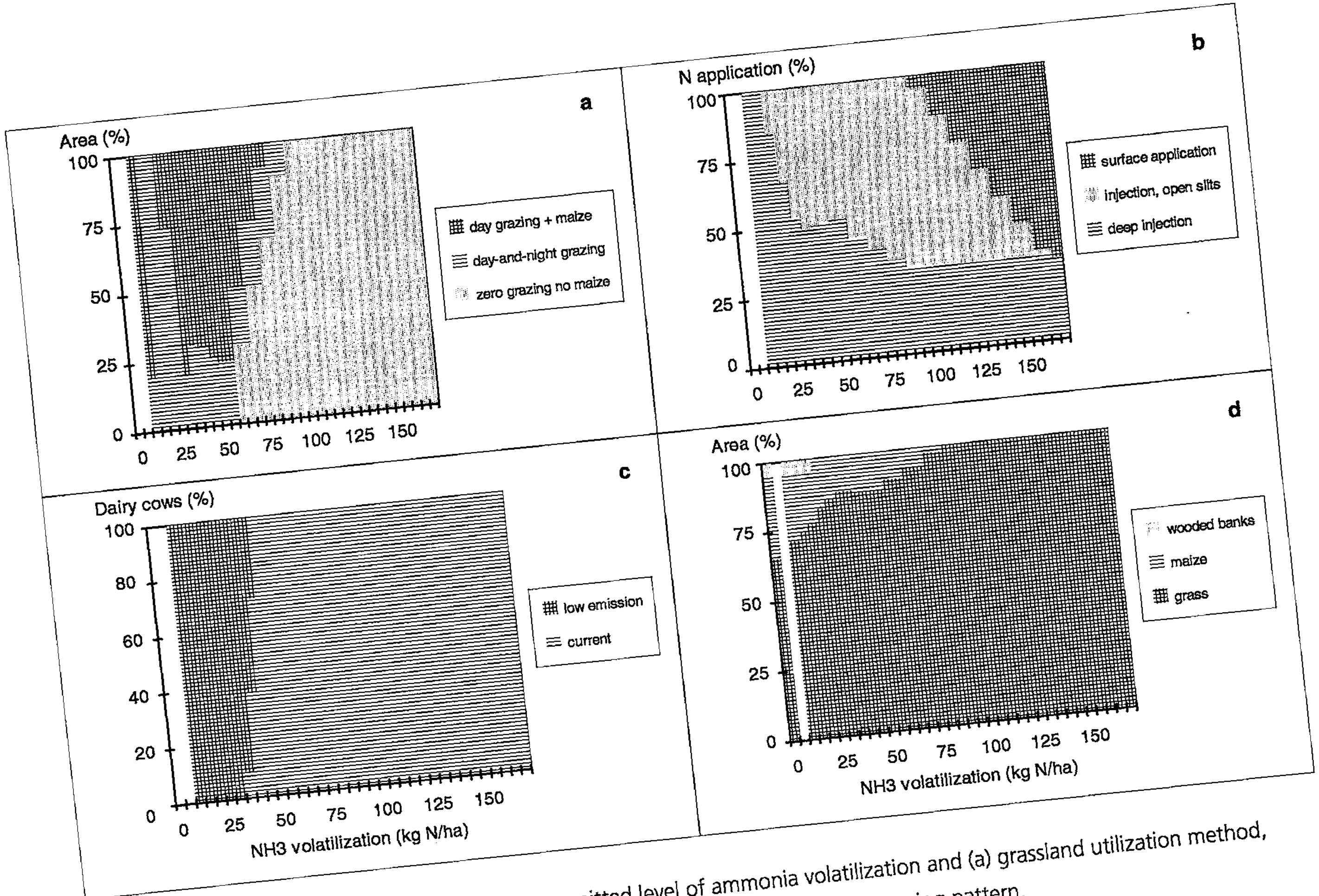

Figure 6.3 Relationship between the maximum permitted level of ammonia volatilization and (a) grassland utilization method, (b) slurry application method, (c) stable and slurry storage type and (d) cropping pattern.

farming system and that aimed at maximum labour income without restrictions are N application rate, the grassland utilization system, the herbage supply level and hence, concentrate purchases, low-emission constructions and the area under maize. The stocking rate is much lower than in the first optimization round, because of the limits on N losses. The policy objectives for the year 2000 can be achieved if a 28 % reduction in labour income is accepted. Most of this reduction is associated with the restriction on volatilization.

6.2.2. The nitrogen policy objectives for the year 2000 in perspective

Reducing N losses to the environment requires a change in dairy farming management. The type of measures required depend on the degree and the type of restrictions imposed. In this subsection, the management changes and their consequences on the environmental and economic performance of the dairy farming system will be analysed, when the restriction on ammonia volatilization is tightened gradually at a fixed leaching loss of 34 kg N (vertical dotted line in Figure 6.1) and when the restriction on nitrate leaching is tightened gradually at a fixed volatilization rate of 30 kg N (horizontal dotted line in Figure 6.1). This analysis explores available options around the fixed criterion (34, 30) and puts these nitrogen policy objectives and their effects in perspective.

Tightening the restriction on ammonia volatilization at a fixed leaching loss of 34 kg N ha^{-1}

All changes in the dairy farming system are directed towards achieving the highest labour income when the restriction on volatilization is tightened from 170 to 0 kg N, at a leaching loss of 34 kg N (vertical dotted line Figure 6.1)

Figure 6.3 presents the changes in grassland utilization in summer (a), slurry application method (b), percentage of dairy cows in standard and low-emission stables (c), and the area allocated to grass, maize, fodder beet and wooded banks (d) under increasingly tighter restrictions on volatilization. Figure 6.4 shows the changes in stocking rate (a), N application rate on grassland, including both inorganic fertilizers and slurry (b) and amount of purchased concentrates (c). Figure 6.5 gives the environmental and economic performance, as indicated by N surplus (a), P surplus (b), milk production per ha (c), labour income (d), the shadow price of volatilization and leaching (e) and the financial costs and returns (f).

The maximum attainable labour income, associated with a volatilization rate of 170 kg N is Dfl 5 200. Grass is used for zero grazing. Slurry is applied by deep injection (30 %) and surface application (70 %). Standard stable and slurry

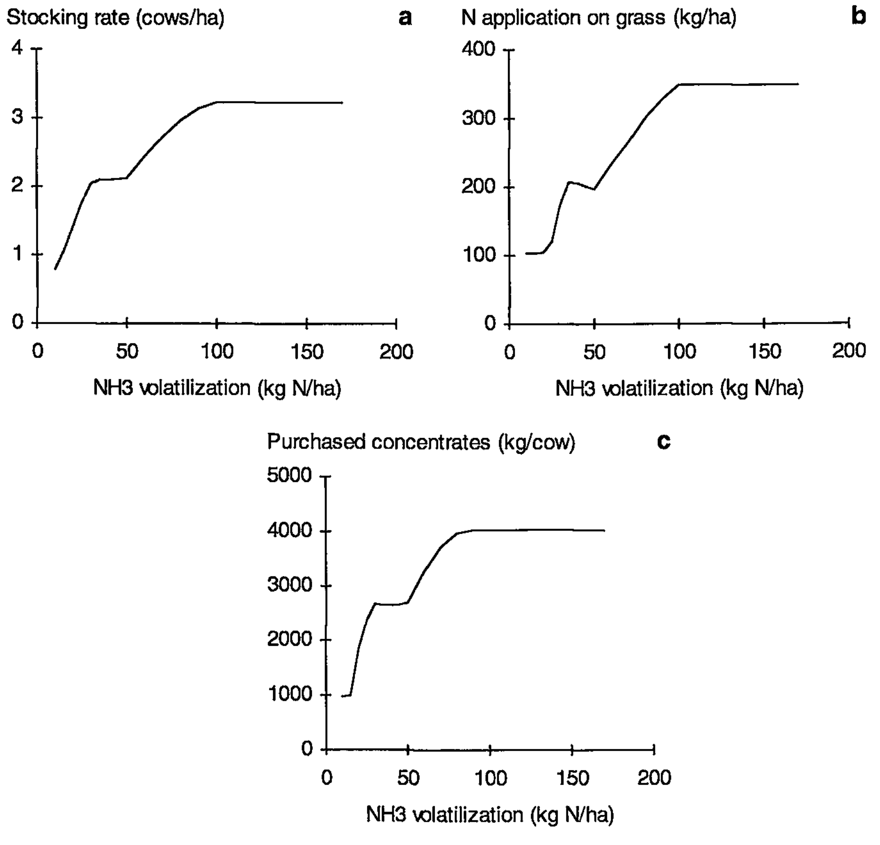

Figure 6.4 Relationship between the maximum permitted level of ammonia volatilization and (a) stocking rate, (b) N application on grassland and (c) purchased concentrates.

storage constructions are used. Stocking rate is 3.23 cows ha^{-1}. Milk production per cow is 8 000 kg. Total N application is 350 kg. The amount of concentrates purchased per cow is 4 025 kg. The herbage supply level is 0.8. The N and the P surpluses are 340 and 29 kg, respectively, and milk production is 25 870 kg ha^{-1}. By tightening the restriction on volatilization from 170 to 100 kg N, surface application of slurry is gradually replaced by injection with open slits (Figure 6.3b), i.e. the cheapest measure to reduce volatilization losses. Restricting volatilization to 100 kg N, does not influence the dairy farming system, only the costs increase by Dfl 100, which is hardly noticeable in Figure 6.5f, but, labour income decreases accordingly (Figure 6.5d). Grass is used for zero grazing while stocking rate, N application and the amount of purchased concentrates remain constant. N surplus decreases with decreasing volatilization rates, because N utilization from slurry applied by injection with open slits is

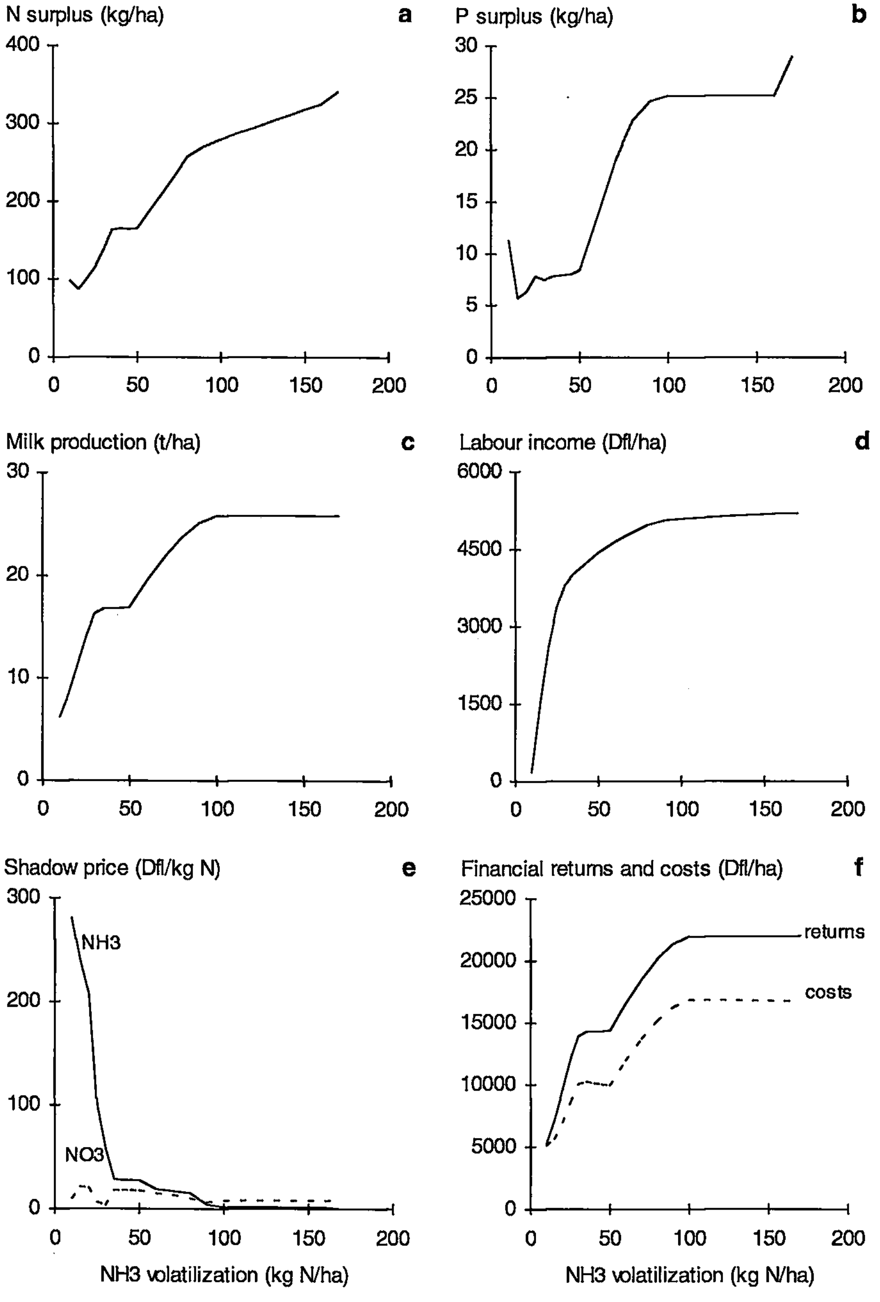

Figure 6.5 Relationship between the maximum permitted level of ammonia volatilization and (a) N surplus, (b) P surplus, (c) milk production, (d) labour income, (e) shadow price of nitrate leaching and ammonia volatilization and (f) financial returns and costs.

more efficient than from surface applied slurry. Hence, less artificial N fertilizer is required to attain the same N supply to herbage. At unrestricted volatilization losses, i.e. 170 kg N, P input with concentrates is higher than at a restriction level of 160 kg N, resulting in a higher P surplus. Concentrates with a high P-content also contain more N (Appendix B). N excretion and thus volatilization, and P surplus are reduced by partly replacing concentrates with a high N-content (type 5: 62 g N kg^{-1}, 12.2 g P kg^{-1}) with those with a lower N-content (type 4: 32 g N kg^{-1}, 6.5 g P kg^{-1}). To meet the protein requirements of the cattle, the amount of concentrates fed increases by a very small amount compared with the total input of 13 tonnes, i.e. 10 kg ha^{-1} (Figure 6.4c). Milk production decreases by 40 kg to 25 830 kg (Figure 6.5d). Labour income decreases by only Dfl 3, because type 4 concentrates are cheaper than type 5. Right down to a volatilization rate of 100 kg N, the shadow prices of ammonia volatilization and nitrate leaching remain constant, i.e. Dfl 2 and Dfl 8 kg^{-1} N, respectively (Figure 6.5e). This implies that relaxing of the restrictions on volatilization and leaching by 1 kg N ha^{-1} will increase labour income by Dfl 2 and Dfl 8, respectively.

By tightening the restriction on volatilization from 100 to 50 kg N, zero-grazing will gradually be replaced by grazing systems (Figure 6.3a). Zero-grazing is the most profitable system when no restrictions are imposed on volatilization (Subsections 6.1.2 and 6.1.3). Restricting volatilization to 90 kg N, leads to the transfer of yearlings to a day-and-night grazing system. Further reduction of volatilization will result in a transfer of calves to day-and-night grazing and subsequently, of cows to day grazing. Yearlings are transferred outside first, because the reduction in volatilization is greatest and in labour income smallest. During summer no slurry is collected inside and only volatilization losses from urine patches occur. The area required for yearlings is larger and hence, less is available for dairy cows, but the latter can still partly be kept inside, resulting in the highest milk production (Chapter 3). Introduction of grazing requires a reduction in N application rates to meet the restriction of 34 kg N on leaching (Chapter 3, Figure 6.4b).

When restricting volatilization from 80 to 50 kg N, herbage supply level is gradually increased from 0.8 to 1.0, which is accompanied by a reduction in concentrate use per cow (Figure 6.4c). The stocking rate (Figure 6.4a) has to be reduced due to the introduction of grazing, reduced N application rates (Figure 6.4b) and an increasing herbage supply level. It decreases by about 30 % while labour income decreases by only 11 %. The N and P surpluses decrease from 260 to 165 and from 23 to 8 kg, respectively (Figures 6.5a-b). The reduction in milk production is proportional to that in stocking rate (Figure 6.5c), as milk production per cow is maintained at 8 000 kg. Labour income decreases from

Dfl 5 000 to 4 450 (Figure 6.5d). At a volatilization rate of 90 kg N, and a leaching loss of 34 kg, the marginal costs for volatilization exceed those for leaching (Figure 6.5e). At a volatilization rate of 50 kg N, the marginal cost of ammonia volatilization and nitrate leaching increase to Dfl 27 and Dfl 18 (kg N)$^{-1}$, respectively.

At a restriction on volatilization of 50 kg N, part of the cows will be transferred to day-and-night grazing. N application rate has to be reduced to meet the restriction on leaching, resulting in a lower milk yield and reduced labour income. Hence, the area under day-and-night grazing is kept as small as possible.

By tightening the restriction on volatilization from 50 to 35 kg N, the dairy farming system hardly changes. Low-emission constructions will be gradually introduced (Figure 6.3c). The N application rate will be about 200 kg. The introduction of low-emission constructions permits a slight increase in N application rate from 195 to 205 kg .

To achieve further reduction in volatilization losses, N application has to be reduced, leading to stocking rates of less than 2 cows ha^{-1}. At a volatilization rate of 30 kg N, N application is 170 kg (Figure 6.4b) and day grazing can be practised again, if all constructions are low-emission. At a volatilization rate of 25 kg N, some of the cows have to be transferred to day-and-night grazing again and at 20 kg N all cattle is under day-and-night grazing. At volatilization rates below 35 kg N, labour income is severely reduced (Figure 6.5d). At a restriction of 15 kg N the marginal costs of ammonia volatilization increase sharply to Dfl 225 (kg N)$^{-1}$ (Figure 6.5e). At a volatilization rate of 35 kg, all measures that reduce volatilization losses and at the same time maintain labour income at a reasonable level, by compensating the diminishing returns with diminishing costs (Figure 6.5f), have been introduced. Further tightening of the restriction leads to returns diminishing faster than costs.

The shadow price of nitrate leaching remains relatively low and fluctuates with the grazing system. Under day-and-night grazing it is higher than under day grazing (Figures 6.5e and 6.3a).

Zero grazing is not combined with feeding maize silage in summer, due to the restriction of 34 kg N on nitrate leaching. Leaching under maize is high when compared to grassland (Chapters 3 and 4) and the costs are higher, because maize cultivation is carried out fully in contract labour, while for grass only silage making is carried out in contract labour. Farm labour is not included, but has to be covered by the calculated labour income.

Day grazing requires some maize cultivation (Figure 6.3d), as maize silage is supplied during the night and cannot be purchased from outside the region.

Right down to a volatilization rate of 35 kg N, maize is only fed during the night in summer and the winter ration consists of wilted silage. At a volatilization rate of 30 kg N, maize is also fed in winter. Below 30 kg, ground ear silage is fed which is produced in the region, replacing part of the purchased concentrates, due to the restriction that all land has to be used. It is cheaper to produce ground ear silage in the region than to purchase it, but then land has to be allocated to maize cultivation, reducing the stocking rate and thus milk production. Hence, concentrates will only be cultivated in the region if land is in surplus. The maximum area of 5 % is covered by wooded banks.

The dairy farming systems selected at volatilization rates of 10 and 0 kg N are not realistic. All land has to be used, but the permitted stocking rate is too small to consume all the fodder produced in the region. Fodder cannot be sold to other regions, nor converted into milk and meat, and hence grass and maize silage accumulate in the region, resulting in an increased N and P surplus (Figures 6.5a and b). A volatilization rate of 5 kg N is not within the solution area (Figure 6.1).

To summarize, this analysis shows that to reduce ammonia volatilization from 170 to 15 kg N, at a permitted leaching loss of 34 kg N, first low-emission slurry application techniques have to be introduced. Subsequently, zero-grazing must be replaced by grazing systems and N application rates have to be reduced to 200 kg ha^{-1}. Low-emission stables and slurry storages must be constructed and finally, N application rates must be reduced to the minimum defined in the model, i.e. 100 kg. At volatilization rates below 35 kg N, the marginal costs of reduction increase sharply and labour income is severely reduced. By only restricting nitrate leaching losses to 34 kg N ha^{-1}, the N surplus may still vary between 90 and 340 kg ha^{-1} and the P surplus between 6 and 29 kg ha^{-1}, depending on the level of ammonia volatilization.

Tightening the restriction on nitrate leaching at a fixed ammonia volatilization of 30 kg N ha^{-1}

All changes in the dairy farming system are directed towards achieving the highest labour income when the restriction on nitrate leaching is tightened from 62 to 14 kg N, at a volatilization loss of 30 kg N (Figure 6.1). The results of the optimization are summarized in Figures 6.6, 6.7 and 6.8, similar to Figures 6.3, 6.4 and 6.5, respectively, with the only difference being that the restriction on nitrate leaching is tightened instead of that on ammonia volatilization.

Maximum attainable labour income is Dfl 3 870, associated with a leaching loss of 62 kg N. Dairy cows are kept in a day grazing system in summer and are supplemented with maize indoors. Young stock is kept under day and night grazing. About 30 % of the area is cultivated with maize and 70 % is grassland.

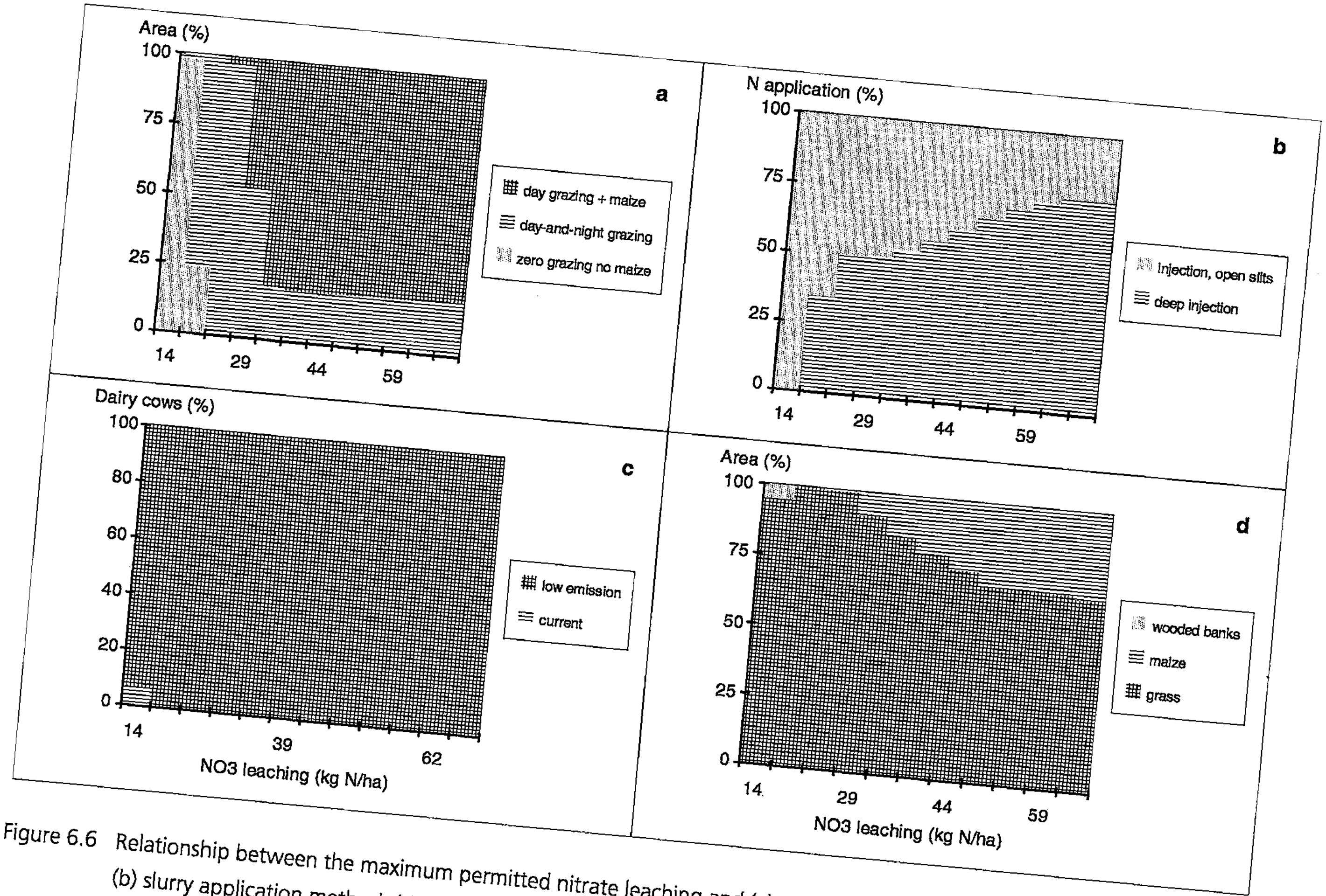

Figure 6.6 Relationship between the maximum permitted nitrate leaching and (a) grassland utilization method, (b) slurry application method, (c) stable and slurry storage type and (d) cropping pattern.

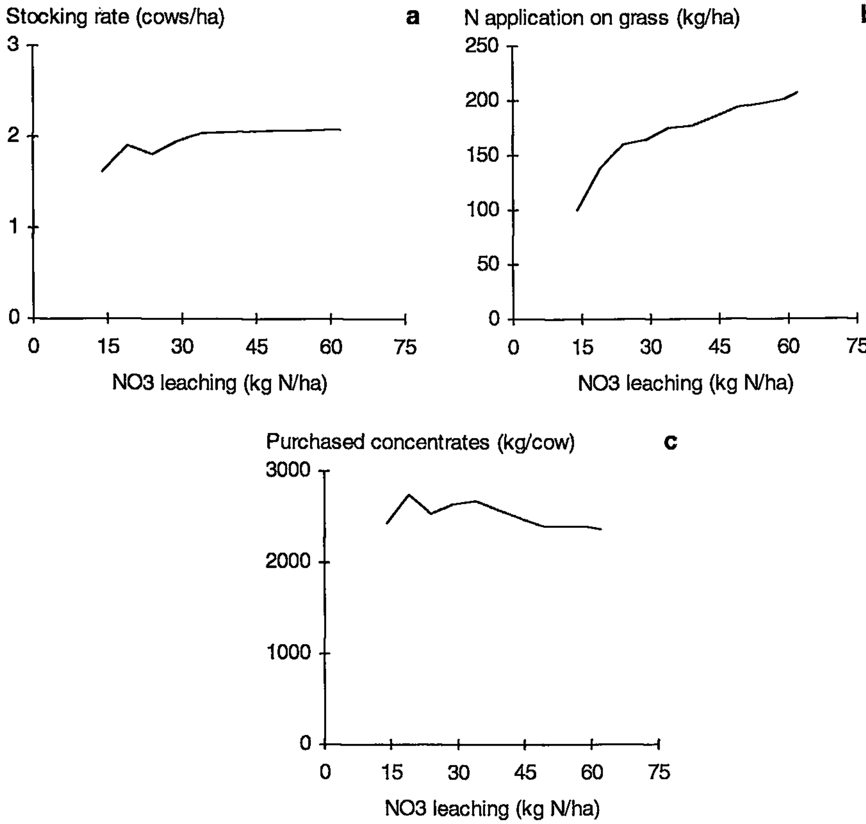

Figure 6.7 Relationship between the maximum permitted nitrate leaching and (a) stocking rate, (b) N application on grassland and (c) purchased concentrates.

All stables and slurry storage systems are low-emission constructions and slurry application is by deep injection and injection with open slits, because of the restriction on volatilization of 30 kg N. The stocking rate is 2.08 cows ha^{-1}. Milk production is 8 000 kg per cow. Total N application, including artificial fertilizer and slurry, on grassland is 205 kg. N application on maize is 150 kg ha^{-1}, applied by deep injection of slurry. The amount of concentrates purchased per cow is 2 365 kg. The daily winter ration for dairy cows consists of 1.6 kg wilted silage, 5.8 kg maize silage and 8.4 kg concentrates with an average N content of 24 g kg^{-1}. Herbage supply level is 1.0 and milk production is 16 650 kg ha^{-1}.

By tightening the restriction on nitrate leaching from 62 to 29 kg N, the area under maize is gradually reduced until it finally disappears from the dairy farming system (Figure 6.6d). Placement of slurry in the rows is introduced at a restriction on leaching of 54 kg N, improving N utilization and conserving the area under maize. N application on grassland is gradually reduced from 205 to

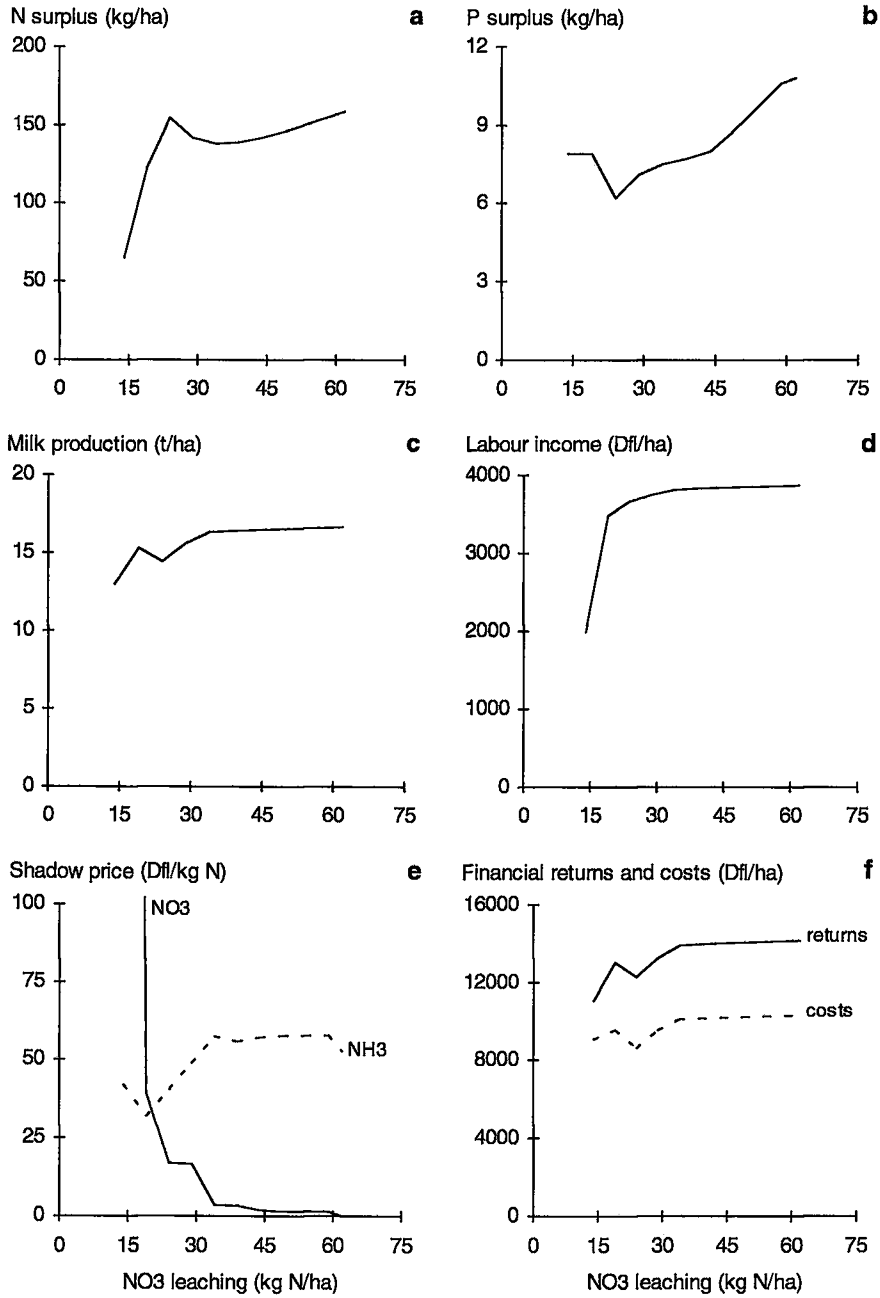

Figure 6.8 Relationship between the maximum permitted nitrate leaching and (a) N surplus, (b) P surplus, (c) milk production, (d) labour income, (e) shadow price of nitrate leaching and ammonia volatilization and (f) financial returns and costs.

165 kg (Figure 6.7b). To keep up stocking rate (Figure 6.7a) and hence, milk production (Figure 6.8c), maize silage fed in winter is partly replaced by wilted silage and partly by concentrates, resulting in a higher concentrate intake per cow (Figure 6.7c). The average N content of concentrates becomes 21 g kg^{-1}, so the increased concentrate purchases do not result in higher N inputs. At a leaching loss of 34 kg N, part of the grass is conserved as hay and fed to the dairy cows in winter at a rate of 1 kg cow^{-1} d^{-1}. More concentrates can be fed if hay forms part of the ration due to its high structural value. Moreover, at a similar N content, the DVE content of hay is relatively high compared with that of wilted silage. The yield of hay is lower than that of wilted silage, but under the restrictions defined, it appears that the feed quality of hay compensates for its low yield. The reduction in N fertilizer purchases more than compensates for the slightly reduced N outputs with milk and meat, resulting in a decreasing N surplus (Figure 6.8a). P surplus decreases because of decreasing P application rates on grassland and a lower P content of concentrates. At a leaching loss of 44 kg N no P fertilizer has to be purchased any more and all P is supplied by slurry. Milk production at a leaching loss of 34 kg N is still 16 360 kg ha^{-1} (Figure 6.8c). Labour income is reduced by only Dfl 120 to Dfl 3 750 (Figure 6.8d). The shadow price of ammonia volatilization is almost constant between leaching losses of 62 and 34 kg N, i.e. Dfl 57. The shadow price of nitrate leaching increases only very slowly to Dfl 4 at a leaching loss of 34 kg N (Figure 6.8e).
By tightening the restriction on leaching from 34 to 24 kg cows are transferred to a day-and-night grazing system (Figure 6.6.a). The area under maize is too small to supply all cows with maize silage in summer and at low N fertilizer application rates, grazing systems are preferred over zero-grazing because of their relatively low volatilization losses. The stocking rate decreases and hence, more N fertilizer has to be purchased to meet the N requirements, which cannot be offset by the lower concentrate inputs.
When nitrate leaching has to be restricted to values below 24 kg N, first cows have to be transferred to a zero-grazing system and at minimum leaching loss the young stock too (Figure 6.6a). All slurry has to be applied by in injection with open slits (Figure 6.6b). Part of the area will be used for landscape purposes (Figure 6.6d). The stocking rate first increases slightly, as under zero-grazing more cows can be kept per ha at the same N application level (Chapters 2 and 3), but finally decreases to 1.62 cows ha^{-1} (Figure 6.7a) at an N application of 100 kg (Figure 6.7b). Concentrate input is 2 430 kg per cow, i.e. higher than in the situation with no restrictions on nitrate leaching (Figure 6.7c). N surplus decreases to 65 kg and P surplus increases to 8 kg (Figures 6.7c-d) due to the

high concentrate input and introduction of some P fertilizer. Milk production is still 13 t ha^{-1} (Figure 6.8c). The increase in milk production does not result in a higher labour income because of the higher costs of the zero-grazing system (Figure 6.8f). Finally, labour income decreases to about 50 % of the maximum, i.e. Dfl 1 980 ha^{-1}. At 20 kg N the shadow price of nitrate leaching exceeds that of ammonia volatilization. At this point, a part of the cattle can again be kept in standard stable and slurry storage constructions (Figure 6.5c), indicating that the restriction on nitrate leaching dominates the farming system. At a target loss of 14 kg N the shadow price of nitrate leaching increases to Dfl 1 100 (Figure 6.8e).

To summarize, this analysis shows that, to reduce nitrate losses from 62 to 14 kg N, at a target volatilization loss of 30 kg N, first slurry applied to maize, must be placed in the rows. Gradually, maize will be replaced by grass and N application reduced to 100 kg. Stocking rate is kept as high as possible by compensating for the lower fodder production with higher concentrate purchases. Labour income decreases only slightly, except at the minimum leaching loss, when it decreases by 50 %. At a leaching loss below 24 kg N, the marginal costs of reducing nitrate leaching increase drastically.

6.3. Integrated dairy farming on sandy soils

In addition to the government nitrogen policy objectives, other goals also play an important role in integrated agriculture, as described in Chapters 1 and 5, where ten goals were defined. It would require a large number of iterations to map the whole solution area for these ten goals, as was done in Subsection 6.1.1 for three goals, and impossible to present the results graphically. Therefore, the restrictions on the ten goal variables have been tightened step-by-step until acceptable values for each were reached. The results describe the contours of the 'accepted area', i.e. that part of the solution area in which all goals have values acceptable to all interest groups (Veeneklaas, 1990). This procedure can be compared to following an indented line in Figure 6.1, starting from point 5 until maximum permitted leaching and volatilization losses and a minimum labour income are achieved. For instance, if the maximum permitted nitrate leaching is 34 kg N, the maximum permitted ammonia volatilization 30 kg N and the minimum permitted labour income Dfl 1 000, the accepted area in Figure 6.1 would be delineated by the lines for 14 and 34 kg N nitrate leaching, 30 kg N ammonia volatilization and a labour income of Dfl 1 000.

Ideally, interested parties, such as policy makers, farmers and environmentalists should participate in the process of tightening the restrictions on the goal

Table 6.4 Extreme values of each of the goals optimized, most favourable values in **bold**, least favourable values in the bottom row and the associated values of the other goals (in rows). All values are expressed per ha.

Goal	NO_3 kg N	NH_3 kg N	N surplus kg N	P surplus kg P	Milk production t	Labour income Dfl	Net result Dfl	Labour h	Cows outside head	Wooded banks % area
NO_3 (min)	**14**	5	129	25	1.6	-3 000	-4 020	33	0	5
NH_3 (min)	81	**0**	237	35	0.0	-4 240	-4 240	0	0	5
N surplus (min)	18	21	**24**	3	10.6	1 120	-670	59	0	0
P surplus (min)	68	48	251	**-8**	10.3	-1 410	-4 070	87	0	0
Milk production (max)	68	116	379	30	**26.4**	5 015	1 270	123	0	0
Labour income (max)	56	178	395	29	26.3	**5 250**	1 520	122	0	0
Net result (max)	103	82	390	8	16.4	4 690	**2 555**	70	2.05	0
Labour (min)	65	0	133	23	0.0	-3 945	-3 945	**0**	0	5
Labour (max)	68	104	372	19	17.1	-565	-4 790	**139**	0	0
Cattle outside (max)	88	97	341	14	15.9	45	-3 130	104	**3.18**	0
Wooded banks (max)	59	0	212	35	0.0	-4 215	-4 215	0	0	**5**
Least favourable value	103	178	395	35	0.0	-4 240	-4 790	0	0	0

variables, as this involves subjective judgement. They should indicate the least acceptable value of each goal, based on information generated during the optimization process: the costs of maintaining a minimum value for one goal in terms of sacrifices on the maximum value for the other goals. In this study, the least acceptable values for restrictions are based on policy objectives, as described in various policy documents (Min. of Agriculture, Nature Management and Fisheries, 1989 and 1993; Min. of Housing, Spatial Planning and Environment, 1989 and 1994; Min. of Transport, Public Works and Water Management, 1989).

First the results of the iteration with no restrictions on the goal variables will be presented (Subsection 6.3.1). Subsequently, the effects of tightening the restrictions on the goals (Subsection 6.3.2) will be given and finally, the dairy farming systems associated with the accepted area (Subsection 6.3.3) will be described.

6.3.1. Extreme values of the individual goals

Table 6.4 gives the extreme values of each individual goal without any restrictions on the other goals and the least favourable values attained. The results for nitrate leaching, ammonia volatilization and labour income were discussed in Subsection 6.1.1. However, Table 6.4 adds a least favourable value for nitrate leaching of 103 kg N instead of 78 kg, when maximizing net result. Minimum N surplus is 24 kg and the maximum is 395 kg. P surplus ranges from -8 to 35 kg. Maximum milk production is 26.4 t. Maximum net result is Dfl 2 555 and the minimum is Dfl - 4 790. Labour input ranges from 0 to 139 hours. The maximum number of cows that can be kept outside in summer is 3.18. The area under wooded banks can reach the maximum of 5 %, set in advance.

The least favourable values presented are rather arbitrary, as they are non-binding and do not force the optimization process in any direction. However, in an optimization process with multiple goals they can be used to guide the user towards setting the boundaries of the accepted area. The least favourable value is selected and given a more acceptable value. This forms the start of the next iteration, in which all goals are optimized again, subject to the new restrictive value. This procedure is repeated until the least favourable value for each of the goals is acceptable.

6.3.2. Tightening the goal restrictions in steps

The results of the successive iterations are summarized in Figures 6.9 a to j. The iteration number is given on the x-axis and on the y-axis the value of the goal considered. The solid line represents the most favourable value and the dotted line the least favourable value of the goal. An arrow indicates the restriction that has been tightened in an iteration and the associated number is its new value. More detailed results are given in Appendix C.

On the basis of N policy objectives and the results in Table 6.4, the restriction on nitrate leaching has been tightened in the second iteration to 34 kg N (Figure 6.9a). Hence, in the second iteration all goals are subject to a maximum leaching loss of 34 kg. Under this restriction, volatilization loss can still be reduced to 0 (Figure 6.9b, iteration 2). Minimum P surplus increases to - 5.4 kg (Figure 6.9c, iteration 2), because in addition to P surpluses, leaching losses have to be considered. Apparently, the lowest leaching losses do not coincide with the lowest P surplus. Minimum N surplus remains 24 kg (Figure 6.9d). Maximum milk production decreases to 25.9 t (Figure 6.9e). Maximum labour income decreases to Dfl 5 200 (Figure 6.9f). The maximum area under wooded banks remains 5 % (Figure 6.9g). The maximum number of cows outside decreases to 3.04 (Figure 6.9h) and maximum net result decreases to Dfl 2 400 (Figure 6.9i). Minimum labour input increases to 2 h and the maximum decreases to 135 h (Figure 6.9j). Reducing nitrate leaching to the policy objective of 34 kg N, influences the best attainable values of most goals somewhat, but not very drastically.

The least favourable value for ammonia volatilization in the second iteration is still 170 kg N (Figure 6.9b, Appendix C). In the third iteration, the maximum permitted ammonia volatilization is set at 30 kg N. Again all goals are optimized, now subject to both a maximum leaching loss of 34 kg N and a maximum ammonia volatilization of 30 kg N. Minimum leaching losses are not influenced by the additional restriction on volatilization (Figure 6.9a). Minimum P surplus increases to -4.0 kg (Figure 6.9c). The minimum N surplus is not influenced, but the least favourable value is improved to 180 kg (Figure 6.9d). This effect would be expected, as both leaching and volatilization are included in the N surplus. Maximum milk production is greatly reduced, i.e. 17.6 t (Figure 6.9e). Maximum labour income decreases to Dfl 3 810 (Figure 6.9f). The maximum area under wooded banks is not influenced (Figure 6.9g). The number of cows outside decreases to 2.6 (Figure 6.9h). The maximum net result decreases to Dfl 1 850 (Figure 6.9i). Minimum labour input does not change, but the maximum decreases to 107 h (Figure 6.9j). Hence, a reduction in ammonia volatilization conflicts with the goals maximum milk production, labour income, net result and labour. The best attainable values of these goals are reduced by 20 to 30 %.

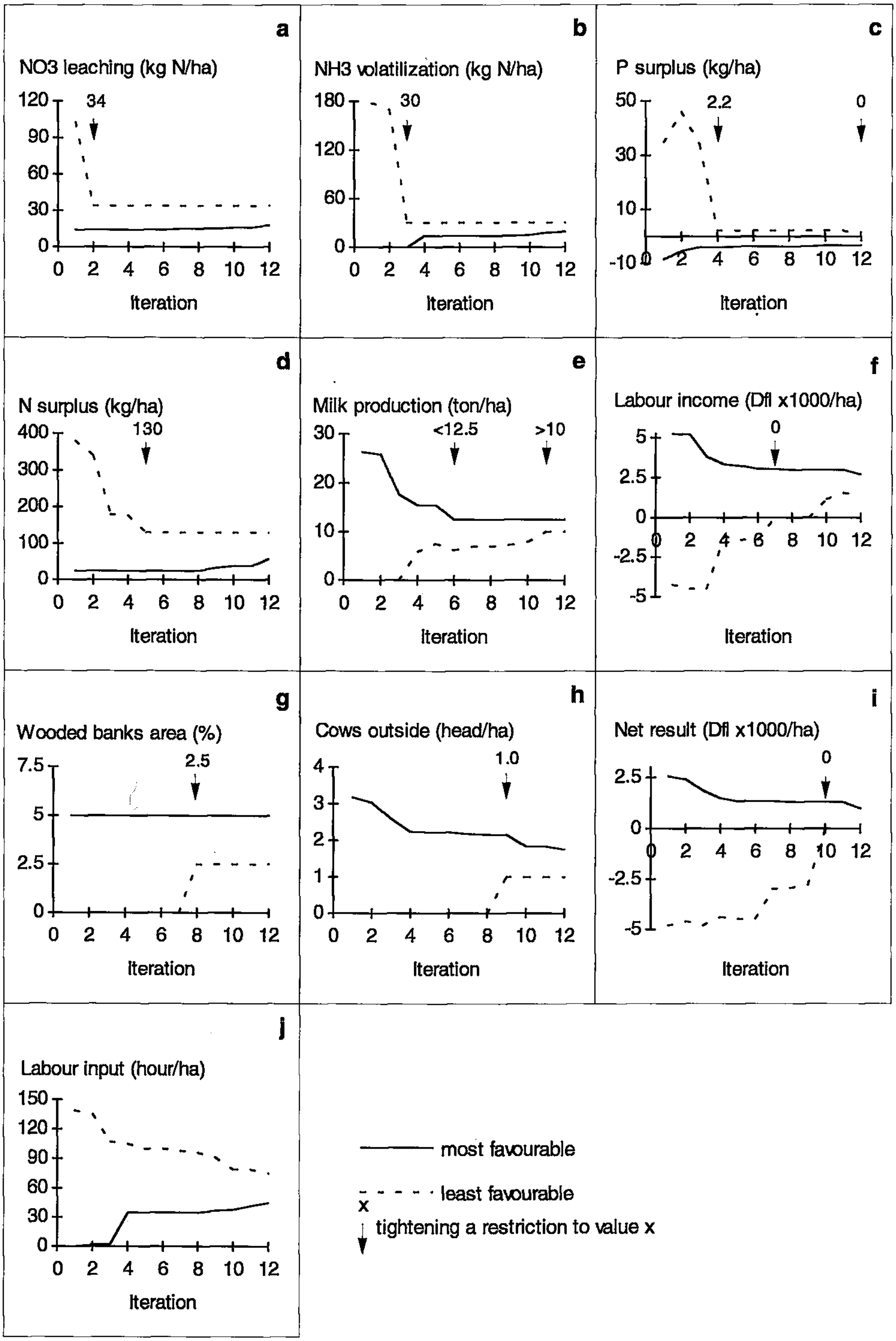

Figure 6.9. The effect of tightening the restrictions on the goals in 12 successive iterations on the most and least favourable values of 10 goals .

A policy objective has not yet been set for P. A value frequently mentioned is 5 kg P_2O_5 kg, which is equivalent to 2.2 kg P (Min. of Agriculture, Nature Management and Fisheries, 1993). Hence, in the next iteration, the maximum P surplus was set at 2.2 kg. The minimum attainable P surplus remains unaltered, but the least favourable value is improved from 34 to 2.2 kg (Figure 6.9c). Minimum nitrate leaching, N surplus and the maximum area under wooded banks are not influenced by this additional restriction. However, minimum volatilization losses increase to 14 kg N, because fodder produced in the region can no longer accumulate, but has to be fed to cattle, resulting in at least some ammonia losses. Maximum milk production decreases to 15.5 t, maximum labour income to Dfl 3 350 and maximum net result to Dfl 1 490. Minimum labour inputs increase to 35 h for the same reason that volatilization increases. The maximum labour input hardly changes. The maximum number of cows outside in summer decreases to 2.25. Hence, reducing P surplus to 2.2 kg, influences the most favourable values of most goals to a limited extent, except for volatilization losses and minimum labour inputs.

The least favourable value for N surplus is still 177 kg, while nitrate leaching and ammonia volatilization have been restricted to acceptable values, implying a rather high N accumulation in the system. To prevent the selection of systems with excessive N accumulation, maximum N surplus was set at 130 kg, corresponding to an accumulation of 62 kg N, if both nitrate leaching and ammonia volatilization are at their limit. Again this does not influence the most favourable values of nitrate leaching, ammonia volatilization, labour and landscape goals. Maximum labour income is reduced to Dfl 3 245 and net result to Dfl 1 342. The additional restriction on N surplus 130 kg influences the best attainable values of most goals only to a limited extent.

At this stage, the environmental goals nitrate leaching, ammonia volatilization, N surplus and P surplus, have satisfying upper boundaries. Other production limiting factors can now be taken into consideration. In the sixth iteration milk production is restricted to the average milk quota on sandy soils in the Netherlands, i.e. 12.5 t (Van Dijk & Van Vliet, 1990). Maximum labour income is reduced to Dfl 3 042. None of the other most favourable values is affected.

Subsequently, economic goals are considered. The lowest labour income is Dfl - 1 395. Hence, in the next iteration minimum labour income is set at Dfl 0. This has hardly any influence on the best values of the other goals. Minimum nitrate leaching increases from 14 to 15 kg N and the maximum number of cows outside decreases from 2.23 to 2.18.

Next, landscape goals are considered, as in some scenario's no cows are outside and no area is reserved for wooded banks. Fixing the minimum area under

wooded banks at 2.5 % of the total, only slightly reduces the best values for labour income to Dfl 2 990, net result to Dfl 1 310 and the number of cows outside in summer and to 2.16. Fixing the number of cows outside in summer at 1, increases the minimum N surplus from 24 to 33 kg. The minimum labour input increases to 37 h and the maximum decreases to 91 h. Hence, for the situation considered, setting minimum values on landscape goals, in addition to environmental restrictions and the implementation of milk qouta, has only a small effect on the most favourable values of the goals.
This leaves some scope for improvement in the economic goals. Minimum labour income was set at 0, but should still cover labour costs. The lowest net result is Dfl - 2 785. Hence, in the next iteration the minimum value on net result is set at 0. This only slightly reduces the best values for all environmental goals, labour inputs and the maximum number of cows outside in summer.
The lowest milk production is 8 t, which is rather low when compared with the average milk quota. Hence, minimum milk production was set at 10 t. This mainly increases minimum ammonia volatilization to 18 kg N and labour input to 42 h.
In the final iteration maximum P surplus is fixed at 0 kg. This implies that P supply equals P yield in products transported form the region. This has small negative effects on labour income, net result, the number of cows that can be kept outside in summer and the N surplus.
Figure 6.9 shows that the largest reduction in the most favourable values of the goals is obtained in iterations 2 to 5. In the following iterations mainly the least favourable values are improved, resulting in convergence of the most and least favourable values. Hence, in 12 iterations the boundaries of the accepted area for dairy farming systems have been explored, as determined by the most and least favourable values of each of the goal variables. A further tightening of any of the restrictions on the goals increasingly reflects the subjective preferences of the user. By continuing the optimization procedure, a policy-maker, a farmer or an environmentalist will end up in different corners of the accepted area by emphasising different goals from the 12th iteration on. If the most and least favourable values are identical only one dairy farming system will be selected. However, indicating the accepted area leaves more space for the realization of individual preferences and shows the position of any user in relation to users with other preferences. In addition, the model results have to be screened with respect to their attainability, as a model is always a simplification of the real world. Not all solutions, which are feasible according to the model may be attainable in practice. It is better to leave some leeway and not to focus on one single model solution (Veeneklaas, 1990). Hence, in this study, the 12^{th} iteration was the final one for establishing the accepted area.

Table 6.5 Extreme values of each of the goals optimized: most favourable in **bold**, least favourable values in the bottom row, the associated values of the other goals (in rows) and the limiting restrictions (underlined). All values are expressed per ha.

Goal	NO_3	NH_3	N surplus	P surplus	Milk production	Labour income	Net result	labour	Cows outside	Wooded banks
	kg N	kg N	kg N	kg P	t	Dfl	Dfl	h	head	% area
NO_3 (min)	**16**	30	68	2.2	10.0	1 565	0	51	1.00	5.0
NH_3 (min)	34	**18**	84	2.2	10.0	1 610	58	51	1.25	5.0
N surplus (min)	19	20	**38**	2.0	10.0	1 545	0	51	1.23	2.5
P surplus (min)	34	29	130	**-3.3**	10.0	1 820	0	60	1.00	2.5
Milk production	32	30	130	2.2	**12.5**	2 085	0	68	1.00	5.0
Labour income (max)	27	30	130	2.2	12.5	**2 990**	1 287	56	1.56	2.5
Net result (max)	25	30	130	2.2	12.1	2 960	**1 306**	54	1.52	2.5
Labour (min)	34	24	100	2.2	10.0	1 290	0	**42**	1.25	5.0
Labour (max)	27	28	130	2.2	12.5	2 425	0	**79**	1.17	2.5
Cattle outside (max)	34	30	130	2.2	12.5	1 950	0	64	**1.84**	2.5
Wooded banks (max)	21	30	111	2.2	10.0	2 090	345	57	1.00	**5.0**
Least favourable value	34	30	130	2.2	10.0/12.	1 545	0	42/79	1.00	2.5

Table 6.5 gives the full results of this last iteration. The bold values again indicate the most favourable values of the goals. The difference between maximizing labour income and maximizing net result has become very small. The difference between minimum and maximum labour input has also been reduced substantially.

The numbers underlined in Table 6.5 indicate the presence of a shadow price, implying that a restriction is limiting the realization of the objective function. Hence, for a minimum leaching loss of 16 kg N, the worst permitted values for ammonia volatilization, P surplus, net result and the number of animals outside in summer are limiting. Although labour income has no shadow price, Dfl 1 565 is the maximum attainable. Minimum ammonia volatilization is limited by the restrictions on nitrate leaching and P surplus. Here, also the values for labour income and net result are the maximum attainable. The minimum P surplus is limited by the restriction on nitrate leaching, N surplus, net result and both landscape goals. Despite the absence of shadow prices, ammonia volatilization and labour income are at their best values. Maximum net result is limited by the restriction on ammonia volatilization, N and P surplus and the area under wooded banks. Nitrate leaching is not limiting.

The trade-offs between the goals can be deduced from Table 6.5. For instance, the trade-off between net result and nitrate leaching is Dfl 1 306 versus 9 kg N (=25-16), that between ammonia volatilization and nitrate leaching 12 versus 18 kg N, and that between P surplus and leaching 5.5 kg P versus 18 kg N. The trade-offs by definition are not linear. Hence, the trade-off between labour income and nitrate leaching does not necessarily have a value of Dfl 145 (kg N)$^{-1}$ over the full range of values for both objectives. To establish its course over that range, new optimizations would have to be carried out with increasingly tighter restrictions on both goals. It is up to the user of the model to decide how far to proceed and which trade-offs are acceptable.

6.3.3. Four scenarios for integrated dairy farming

In this subsection, the dairy farming systems selected by the most favourable values in the preceding subsection will be discussed with respect to four goals: nitrate leaching and ammonia volatilization, which represent the nitrogen policy goals in the year 2 000; P surplus, which serves as an instrument to reduce P losses; and net result, which represents an economic goal, also considering labour inputs. N surplus serves as a restriction on accumulation and is not a separate goal. Maximum accumulation is 82 kg, as the minimum total N loss by leaching, volatilization and denitrification, established in further optimizations, is 48 kg. Milk production ranges between 10 and 12.5 t. The results for maximization of labour income are close to those for maximization of net result. Discussion of one of these goals therefore will suffice. Labour input is not a goal in itself, but Figure 6.9j shows its boundaries and the employment opportunities in dairy farming in the region. In this study it has been assumed that it is more important to respect the lower bounds on landscape goals, than to maximise them. The four scenarios are all part of the accepted area as established in the 12th iteration.

Figure 6.10 shows land allocation under the four scenarios. Table 6.6 presents a summary of some other characteristics of the selected dairy farming systems.

In the first scenario (Figure 6.10a), minimizing nitrate leaching, 95 % of the area is in grassland and 5 % is occupied by wooded banks. Day-and-night grazing is practised on 39 % of the land and 15 % is used for zero-grazing without maize supplementation. About equal parts of the area are used for ensiling grass, cut at 4 t and for production of artificially dried grass. Maize is not cultivated, as leaching losses from land under maize are much higher than from grassland. N application on grassland is 100 kg. In addition to slurry, 36 kg N and 3.5 kg P fertilizer have to be purchased. P fertilizer purchases are very low, because P application is based on replacement of the amount harvested in products. Total concentrate use is 3 456 kg, of which 53 % is produced in the region, i.e. artificially dried grass. To meet the restriction on P surplus, P inputs with fertilizer and/or concentrates have to be limited. Fertilizer application is already low. Hence, part of the concentrates has to be cultivated in the region. Production of artificially dried grass is the only option, in the absence of maize cultivation. In winter this is the only type of concentrate available, concentrates are purchased for the summer period. Stocking rate is 1.31 dairy cows, of which 78 % produce 8 000 and 22 % 6 500 kg milk per year. The area for grazing is just sufficient to have 1 cow outside in summer. All cows are housed in low-emission stables. To compare the scenarios, three efficiency indicators have been defined, one economic and two environmental: labour income per t milk, milk production per kg N input and milk production per kg P input. Milk is the main output of dairy farming. Labour income reflects the revenues minus the costs. Hence, labour income per unit milk produced is an indicator of the economic performance of the system. Milk production per kg N input and milk production per kg P input are measures of the efficiency of N and P use. In the first scenario, labour income is Dfl 157 t^{-1} milk, and milk production is 79 kg per kg N input and 752 kg per kg P input.

In the second scenario (Figure 6.10b), minimizing ammonia volatilization, 67 % of the area is in grassland. Maize is cultivated continuously on 16 % and maize

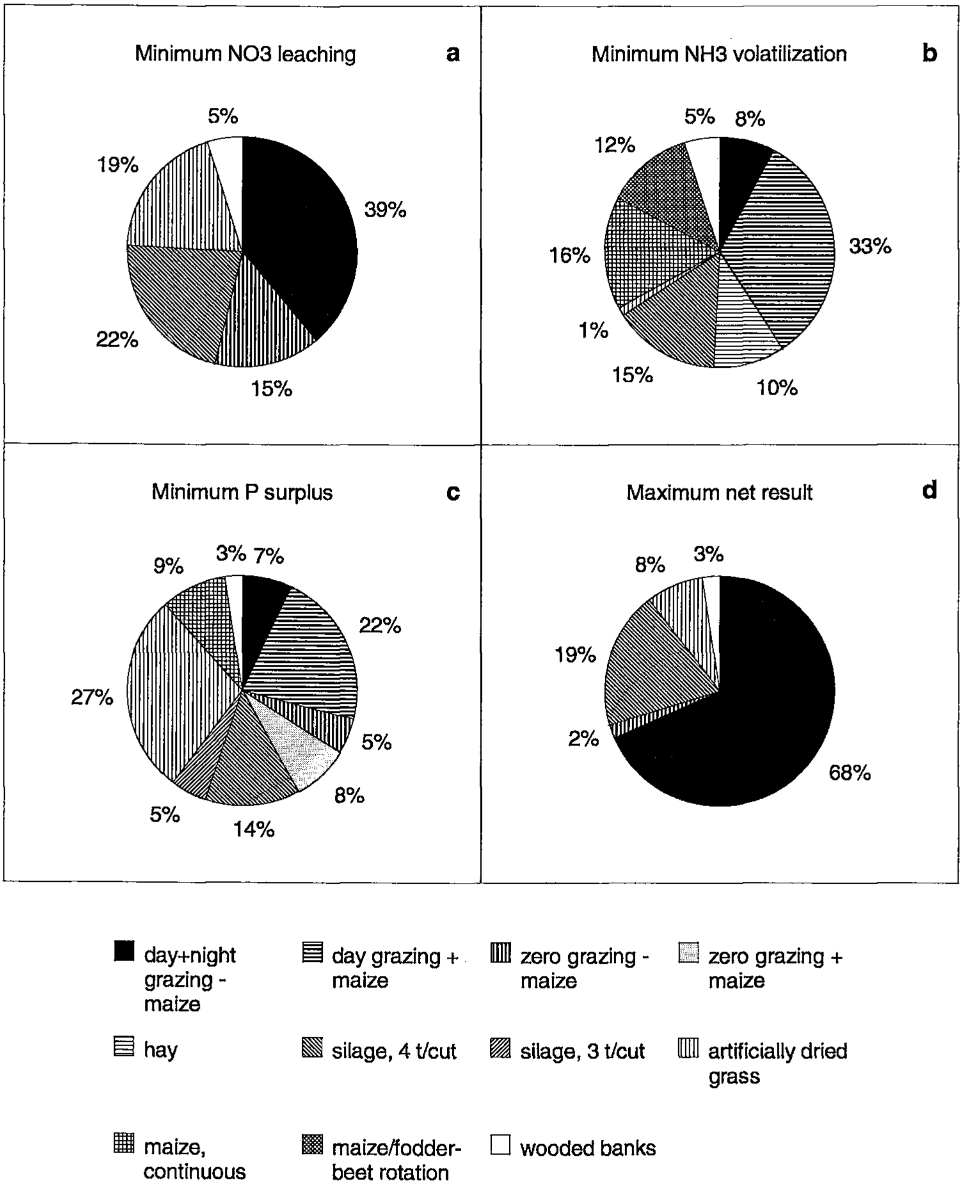

Figure 6.10 Land allocation to selected production techniques under four scenario's in dairy farming.

in rotation with fodder beet on 12 %. Again 5 % of the area is occupied by wooded banks. Day grazing with maize supplementation is practised on 33 % of the area and 8 % is used for zero grazing without maize supplementation. Grass silage cut at 4 t is conserved from 15 % of the area, hay from 10 % of the area and artificially dried grass from 1 % of the area. Average N application on grass is 160 kg. On the area grazed and the associated minimum area cut for conservation (Chapter 5) N application is 100 kg (Table 6.6) to meet the restriction on leaching loss. However, N application is 200 kg on 6 % of the area, which is used for conservation as silage, and 350 kg on 16 % of the area, used for conservation of silage and hay. Higher N application rates than in the previous scenario are permitted to meet the restriction of 34 kg N on leacing. For minimum ammonia volatilization, products with variable N contents are required to minimize N excretion. The DVE surplus in the winter ration of dairy cows and young stock is very low. In this case, a combination of wilted silage with a low and a high N content leads to lower volatilization losses, than wilted silage with an average N content. Maize is fertilized with slurry, placed in the row, and some additional P fertilizer to compensate for the P removed from the field. In addition to slurry, 72 kg N and 7 kg P fertilizer are purchased. Maize

Table 6.6 Characteristics of dairy farming systems in four scenarios.

Characteristic	Unit	Min. NO3 leaching	Min. NH3 volatilization	Min. P surplus	Max. net result
N application					
- fresh grass	kg N	100	100	100-350	100-400
- conserved grass	kg N	100	100-350	100-400	100-450
- maize*	kg N		130;slurry	80;slurry	
- maize/fodder beet*	kg N		100;slurry		
N fertilizer	kg N	36	72	133	98
P fertilizer	kg P	3.5	7.0	6.4	2.3
Stocking rate	cows	1.31	1.25	1.45	1.52
Cow 8 000 kg	%	78	100	100	100
Cow 6 500 kg	%	22			
Concentrates					
- total	kg	3 456	2 545	4 133	3 977
- grown in region	%	53	77	81	26
- per cow	kg	2 638	2 036	2 850	2 616
Low-em. construction	% cows	100	100	100	62
Labour income/milk	Dfl t^{-1}	157	161	151	243
Milk/N input	kg/kg N	79	70	62	60
Milk/P input	kg /kg P	752	781	1 212	806

* inorganic N in slurry

yield is 14.25 t with an N concentration of 13 g kg^{-1}. After maize, a catch crop is grown to reduce leaching losses. Stocking rate is 1.25 and all cows produce 8 000 kg milk. Total concentrate use is 2 545 kg of which 78 % is produced in the region. Concentrates consist of a small part of artificially dried grass (115 kg), fodder beet (610 kg) and ground ear maize (1250 kg). All cows are housed in low-emission stables. Labour income is Dfl 161 t^{-1} milk, i.e. slightly higher than under the previous scenario. However, milk production per kg N input is lower and per kg P input higher, being 70 kg milk kg^{-1} N and 781 kg milk kg^{-1} P, respectively

In the third scenario (Figure 6.10c), i.e. minimization of the P surplus, grassland occupies 88 % of the total area, of which 42 % is used for fresh consumption and 46 % for conservation. All four grassland utilization methods are selected. Day grazing with maize supplementation covers about half the area used for fresh consumption, i.e. 22 %. A large part of the area used for conservation, i.e. 27 % of the total area, is conserved as artificially dried grass, 14 % is used for production of wilted silage cut at 4 t and 5 % for wilted silage cut at 3 t. Maize is cultivated continuously on 9 % of the area and 3 % is occupied by wooded banks. N application on grassland used for feeding in summer for zero-grazing, day grazing and day-and-night grazing the values are 350, 130 kg and 100 kg, respectively. One cut is used for conservation. On the areas used for production of artificially dried grass, N application is 400 kg. Wilted silage cut at 4 t is grown with 350 and wilted silage cut at 3 t with 300 kg N. N application on maize is 80 kg, resulting in a yield of 12.7 t and an N concentration of 11 g kg^{-1}. Slurry is injected in the row. After maize, a catch crop is grown. In addition to slurry, 133 kg N and 6.4 kg P fertilizer are purchased. Stocking rate is 1.45 and all cows produce 8 000 kg milk. The total amount of concentrates fed is 4 133 kg, of which 81 % is grown in the region, consisting of artificially dried grass. The area used for grazing just meets the restriction on the number of cows outside. All cows are housed in low-emission constructions. Labour income per t milk is Dfl 151 and milk production per kg N and P input is 62 and 1 212 kg, respectively. The economic and the N efficiency indicators are less favourable than in the scenarios for nitrate leaching and ammonia volatilization, but the P efficiency indicator has a more favourable value. The scope provided by the target leaching and volatilization losses is used almost completely.

In the fourth scenario, labour income is maximized. Grassland occupies 97 % of the total area and wooded banks 3 % (Figure 6.10d). Day-and-night grazing is practised on 68 % of the area and zero-grazing without maize supplementation on 2 %. Day-and-night grazing is the cheapest way of keeping dairy cattle and requires least labour. If environmental restrictions can be met it is a cheap method of milk production. On 19 % of the area grass is made into wilted silage cut at 4 t and on 8 % conserved as artificially dried grass. N application on the area grazed is 100 kg, on the area used for zero grazing 350 kg and on the area used for production of grass for artificial drying 450 kg N. At least one cut is conserved as wilted silage. N and P fertilizer purchases are 98 and 2 kg, respectively. Stocking rate is 1.52 cows, producing 8 000 kg milk. The total amount of concentrates used is 3 977 kg, of which 26 % is produced in the region, again in the form of artificially dried grass. Only 62 % of the cows is housed in low-emission stables. Labour income per tonne milk is Dfl 243 and milk production per kg N input is 60. Milk production per kg P input is 806.

Comparing economic and environmental performance of the selected systems under the various scenarios, illustrates the conflict between economic, nitrogen and phosphorus objectives. Economic and environmental performance of the scenarios for minimum nitrate leaching and minimum ammonia volatilization are similar. Hence, these goals are not conflicting, although there are considerable differences between the selected dairy farming systems. Under the scenarios for minimizing N losses, labour income per tonne milk is only 65 % of that achieved when maximizing net result and milk production per kg P input is about 63 % of that when minimizing P surplus. Under the scenario with a minimum P surplus, economic performance is 62 % of that under maximum net result and milk production per kg N input is 83 % of that when minimizing N losses. Under the scenario for maximum net result, milk production per kg P is 67 % of that under minimum P surplus and milk production per kg N is 80 % of that under minimum N losses.

This analysis shows that within the accepted area, where each combination of goal variables is acceptable to each of the interested parties, many different dairy farming systems are possible. It depends on the preferences of the model user which scenario is selected. A few general characteristics are: low N application on grazed grassland associated with the restriction on nitrate leaching, a large proportion of the animals housed in low-emission stables associated with the restriction on ammonia volatilization and a substantial part of the concentrates produced in the region associated with the restriction on P surplus.

7. Optimization of production on the experimental dairy farm 'De Marke'

The experimental farm 'De Marke' is a dairy farm integrating environmental and economic goals. It was designed to develop an experimental dairy farming system for sandy soils that at least meets the environmental objectives for the year 2000. It was established in 1991 and serves both as a research and a demonstration project. Based on information about nutrient flows and losses, an initial farm lay-out was designed (Biewinga et al., 1992). The results from monitoring and research and continuous comparison of theoretical concepts and on-farm results guide modifications in farm structure and management to more fully realize the objectives. This process is called prototyping (Vereijken, 1992).
The prototyping method applied at 'De Marke' aims to design integrated dairy farming systems, giving priority to environmental goals. The Dairy Farming Model developed in this study can be used for the same purpose. Both methods are still being refined to improve the results. By applying both to the same situation and comparing the results, it can be assessed whether or not (i) the Dairy Farming Model, initialized for a specific situation, gives realistic results for that situation and (ii) the farm lay-out and specific measures taken at 'De Marke' to realize the goals set in advance based on the prototyping method, are appropriate.
Therefore, the specific situation and the current dairy farming system at 'De Marke' are first described (Section 7.1). The Dairy Farming Model developed in this study has been adapted to the situation at 'De Marke' (Section 7.2). The relationship between N application and crop yield for grass, maize and fodder beet has been studied for several years at 'De Marke'. The results provide a more solid basis for calculations for this specific site than the average data used in the models so far. In Section 7.3, the system in use at 'De Marke' was simulated by fixing the production techniques at those practised currently. Simulation results were compared with farm data, testing (i). Subsequently, dairy production has been optimized taking into account site-specific characteristics, environmental policy objectives and a wide range of production techniques (Section 7.4). Finally, the effect of measures taken at 'De Marke' to reduce nutrient emissions was evaluated (Section 7.5), testing (ii).

7.1. 'De Marke': goals, norms and the dairy farming system

The goals, norms and initial dairy farming system have been extensively described by Biewinga et al. (1992) and are only summarized here.

The basic goal of 'De Marke' is to develop and demonstrate a dairy farming system that meets future environmental requirements, has a milk production per ha at least equal to the average milk quota on sandy soils in the Netherlands and is economically viable. The emphasis is on nutrient management. Goals related to energy and water use, emission of greenhouse gases, use of pesticides, nature and landscape features and animal welfare are considered secondary. They have not been considered in this study, as they have not been quantified in the models so far.

Milk production should be at least 12 t ha^{-1}. For research reasons, the farm is rather large compared with the size of average farms: it occupies 55 ha, has 80 cows and a milk quota of 680 t. The farm is situated on a sandy soil with a low water holding-capacity and a deep ground-water table. Irrigation is possible on part of the land and is often necessary to achieve reasonable grass yields. Grassland occupies 31 ha, fodder beet 6 ha and maize 18 ha, of which 4 ha is harvested and conserved as ground ear silage and 14 ha as whole plant silage.

Environmental target values have been derived from government policy as described in various reports, particularly in the National Environmental Policy Plan (Min. of Housing, Spatial Planning and Environment, 1989), the Nature Policy Plan (Min. of Agriculture, Nature Management and Fisheries, 1989) and the Third Note on Water Economy (Min. of Transport, Public Works and Water Management, 1989). The first five years of 'De Marke' have been directed towards achieving the norms for the year 2000, while in the second phase the norms for the year 2010 will come to the fore. Maximum permitted ammonia volatilization from animal manure is 30 kg N ha^{-1}. Additionally, 14 kg N may volatilize from crops, conserved forages and animals. As the latter processes were not considered in the models, 30 kg N was used as target value. Maximum permitted nitrate concentration in the ground-water is 50 mg l^{-1} at 2 m below the ground-water table. At an annual rainfall surplus of 300 mm, this is equivalent to 34 kg N ha^{-1}. Accumulation in soil organic matter has been assumed to be zero. Denitrification has to be limited to 47 and emission of dinitrogen oxide to 3 kg N ha^{-1} (Biewinga et al., 1992). Adding up all the losses as quantified for 'De Marke' results in an annual N surplus of 128 kg ha^{-1}. Hence, it is estimated that the targets for ammonia volatilization and nitrate leaching will be met at an N surplus of 128 kg. In the Dairy Farming Model emission of dinitrogen oxide is not considered and denitrification is calculated only as a percentage of nitrate leaching, whereas at 'De Marke' denitrification rate in relation to land use and grazing has also been quantified. This probably results in over-estimating of N accumulation and underestimating of denitrification by the model. Hence, nitrate leaching, ammonia volatilization and N surplus have been considered explicitly, but denitrification and accumulation have not been estimated separately.

The norm for P is to maintain equilibrium (P supply = P yield in the harvested crop + ecologically acceptable losses). The ecologically acceptable P concentration in surface water and the upper layer of the ground-water is 0.15 mg P l^{-1}. Where the P status of the soil is 'sufficient', this would result in an annual P surplus of 0.45 kg ha^{-1}. The permitted K surplus is related to EU norms for drinking water, but this falls outside the scope of this study and will not be discussed.

The dairy farming system at 'De Marke' differs from the current system in the following aspects:

livestock	- milk production level per cow is high, about 8 500 kg yr^{-1}; - young stock is kept only for replacement of dairy cows, the replacement rate being 25 %;
ration	- in summer: based on day grazing with supplementation of whole plant maize silage; - in winter: purchased concentrates are partly replaced by home grown feeds like fodder beet and ground ear silage;
housing	- stable with a closed coated floor, a dung scraper and a 'urine ditch';
slurry	- slurry storage covered; - all slurry produced has to be applied on the farm; - application in spring and summer by deep injection and injection with open slits;
cropping pattern	- choice of crops is based on an adequate energy:protein ratio and on providing replacements for concentrates; - all roughage is produced on the farm; - permanent grassland around farm buildings and rotation of grass, maize and fodder beet on part of the farm; - a catch crop is grown after maize;
fertilization	- limited N application rates, no P fertilizer input; - on grassland in rotation with maize, P application exceeds P requirement and on maize, P application is lower than P requirement, to prevent excessive N rates on maize; this requires building up P reserves during the grassland period to be used in the maize period.

7.2. Initialization of the TCG models with data from 'De Marke'

Since 1990, N fertilizer experiments have been conducted at 'De Marke' to study soil production capacity and the relationships between N application, N uptake and crop yield. Relationships based on these experimental data, have replaced those originally used in the TCG models for grass, maize and fodder beet. The soil at 'De Marke' is very heterogeneous with respect to water and N supplying capacity (Biewinga et al., 1992). The 'average' situation has been used in this study.

Figure 7.1 presents the relationships between N uptake and grass yield (a), and between N application and N uptake (b), as originally used in GRASMOD and obtained from N fertilizer experiments on various fields at 'De Marke' during the period 1990-1993 (Baan Hofman & Ten Holte, 1992 and 1995; Baan Hofman, AB-DLO pers. comm.). The lines in Figure 7.1a represent yields at cuts of 1 700, 2 300 and 3 000 kg DM. The experimental data refer to annual yields with varying yields per cut. All treatments in the experiments at 'De Marke' were cut at the same time, resulting in lower yields per cut and per year at low N rates. Generally, the experimental data agree reasonably well with the relationships in GRASMOD and hence, these were not changed.

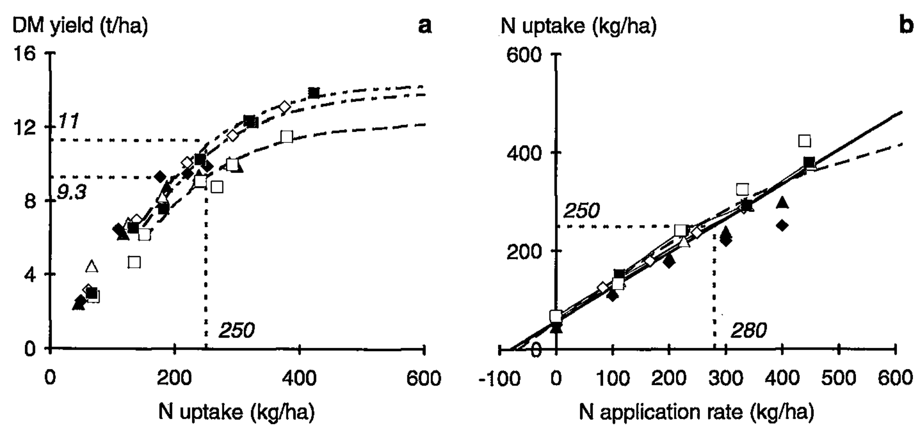

Figure 7.1 The relationships between N uptake and herbage dry matter yield (a) and between N application and N uptake (b) as originally used in GRASMOD (a: _ _ _ 1 700, _ . _ . _ 2 300, _ .. _ .. _ 3 000 kg per cut; b: _ _ _ overall relationship) and according to experimental data at 'De Marke' over the period 1990-1993 (symbols). The solid line in b was used in model calculations for 'De Marke'.

The dotted line in Figure 7.1b represents the relationship between N supply and N uptake used in GRASMOD. It overestimates the apparent N recovery at low N rates at 'De Marke'. Figure 7.1b clearly shows differences in this relationship between fields and years. Average N recovery was 70 %, represented by the bold solid line. The original relation in GRASMOD has been replaced by this one. Average N uptake without fertilizer application was 56 kg. In the initial farming system at 'De Marke', an N application rate of 250 kg was considered the maximum for grassland, based on a day grazing system and the target for nitrate leaching. However, this was based on an assumed N uptake of 140 kg without fertilizer application. The lower N supply from the soil observed in the experiments probably results in lower leaching losses when no fertilizer is applied. In GRASMOD this was estimated at 13 kg N at an N uptake without fertilizer application of 150 kg. It was assumed that at an N uptake without fertilizer application of 56 kg, nitrate leaching is 5 kg N. In view of day grazing and the target for nitrate leaching, an N application rate of 325 kg is now permitted. It is assumed that leaching losses from fertilizer are not influenced by mineralization from soil organic matter.
From 1992 to 1994, the average N application rate at 'De Marke' was 280 kg ha^{-1} (Hilhorst, 1995). Figure 7.1b shows that this results in an average N uptake of 250 kg and Figure 7.1a relates this uptake to a gross herbage yield of 9.3 to 11.0 t, depending on grassland utilization method, with an average of 10.2 t. After correction for grazing and harvest losses, average net herbage yield is 9.3 t. The average herbage yield realized over the three years was also 9.3 t (Hilhorst, 1995). The yields derived from Figure 7.1 require sufficient water supply, which can only be obtained under irrigation or in wet years. In practice, only the grassland around the farm buildings can be irrigated. Hence, about 20 % of the area under grass cannot be irrigated. As the calculated yield, assuming all grassland is irrigated in dry years, equals the measured yield, with at most 80 % of the grassland irrigated, the model may slightly underestimate grass yields.
For maize, data from fertilizer experiments were only available for four fields in two dry years, 1990 and 1991 (Figure 7.2; Baan Hofman & Ten Holte, 1992 and 1995; Ten Holte, AB-DLO pers. comm.). For 1992 and 1993 average N uptake and maize production on fields used in normal practice at 'De Marke' were known (Figure 7.2a; Hilhorst, 1995). The dotted line in Figure 7.2a represents the relationship according to a non-orthogonal hyperbola (Chapter 4). However, the experimental data are best represented by a straight line, i.e. maize with a constant N concentration of 14.3 g kg^{-1}. Water availability was probably more

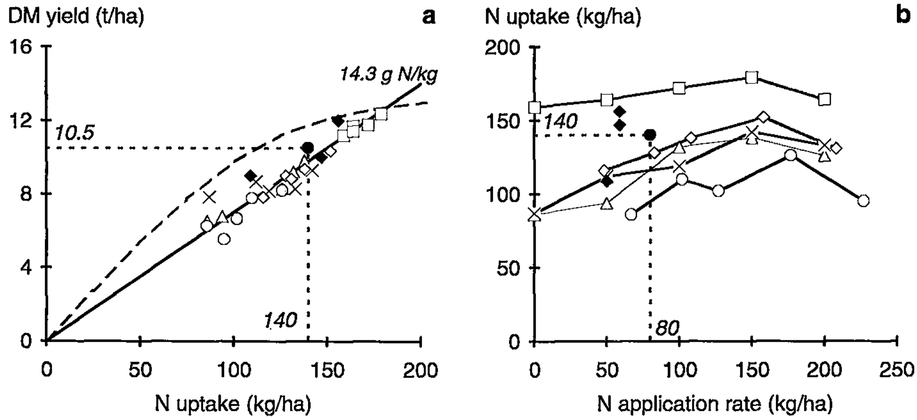

Figure 7.2 The relationship between N uptake and maize dry matter yield (a) and between N application and N yield (b) as originally used in the TCG for maize (a: – – –) and according to experimental data (1990-1991, open symbols) and data from whole fields (1992-1993, ♦) at 'De Marke'. The symbol ● indicates the value used in model calculations for 'De Marke'.

limiting than N supply. This was also the case, however to a lesser extent, in the years 1992 and 1993, as then N was diluted to a content of about 12.5 g kg^{-1}. Based on the data in Figure 7.2a, average maize yield for 'De Marke' was estimated at 10.5 t and the associated N concentration at 13.3 g kg^{-1}, resulting in an N uptake of 140 kg. It has been assumed that if irrigation is possible, the non-orthogonal hyperbola applies to the situation at 'De Marke', implying that at an N uptake of 140 kg, a yield of 11.8 t can be attained.

The experimental relationships between N application and N uptake are shown in Figure 7.2b. Apparent N recovery varied between 10 and 50 %.

The procedure to calculate N application required to reach a certain uptake has been described in Chapter 4. Maize production techniques have been characterized by several indices (Section 4.1). For 'De Marke' the production technique is defined as follows: N concentration in maize is 13.3 g kg^{-1} (S=1); maize only receives slurry and no inorganic fertilizer N (N=4); slurry is injected (A=1, R=1); a catch crop is grown (W=2) and maize can be harvested both for whole plant silage and for ground ear silage (Q=1,2). The amount of N in the upper soil layer has to be initialized (Chapter 4). At 'De Marke', the amount of organic N in the upper 50 cm of the soil is 6 250-7 750 kg, with an average of 7 000 (Biewinga et al., 1992). The effect of a catch crop has been established experimentally (Aarts, 1994a; Ten Holte, AB-DLO pers. comm.). On average, the above ground biomass of the catch crop Italian rye-grass was 2 300 kg dry matter. In one year root biomass was also measured and amounted to 1 730 kg dry matter. In that year the above ground biomass was high: 3 250 kg. The measured shoot:root ratio and N concentration were applied to the average situation. This resulted in an estimated total N uptake of 80 kg, if sufficient N is available after harvesting maize. In the TCG this was translated in a maximum uptake of 80 kg N by a catch crop with an apparent recovery of residual soil organic N of 70 %, similar to that for grass in general at 'De Marke'.

The TCG for maize was initialized with the data described. According to the model, N application should be equivalent to about 80 kg inorganic N to attain an N uptake of 140 kg. N uptake without fertilizer application is 110 kg. This includes N becoming available after breaking up grassland and after cultivation of a catch crop. Apparent recovery of applied inorganic N is 37 %.

Experimental data for fodder beet for two years were also available together with average yields for 1992 and 1993 from fields used in normal practice at 'De Marke'. (Figure 7.3; Baan Hofman & Ten Holte, 1992; Hilhorst, 1995). The relationship between N uptake and crop yield according to the original TCG is shown by the dotted line (Figure 7.3a). Experimental data from 'De Marke' show large differences between years. In 1991 the crop failed due to inadequate management and these data have been omitted. From the limited data set it has been derived that average maximum dry matter yield, including beet root and leaf, is about 18.3 t, i.e. Ymax in the formula for the non-orthogonal hyperbola

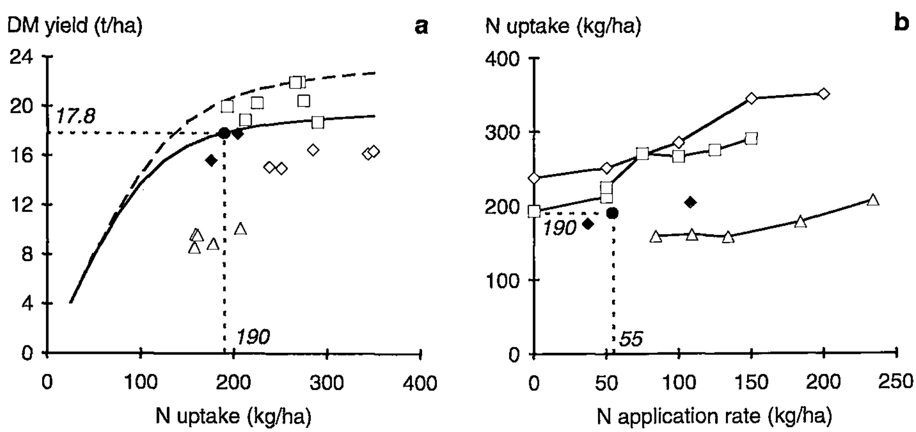

Figure 7.3 The relationship between N uptake and dry matter yield (a) and between N application and N yield (b) as originally used in the TCG for fodder beets (a: – – –) and according to experimental data (1990-1992, open symbols) and data from whole fields (1992-1993, ♦) at 'De Marke'. The symbol ● and the solid line in a indicate the value and relationship used in model calculations for 'De Marke'.

(Section 4.2). The values of the other parameters as defined in Section 4.2 were left unchanged. Average crop yield, which is below the maximum, was set at 17.8 t. According to the non-orthogonal hyperbola, this is associated with an N uptake of 190 kg. If all other parameters in the TCG for fodder beet remain unaltered, N uptake without fertilizer application is 150 kg. The required N application rate for an uptake of 190 kg is equivalent to 55 kg inorganic N and the apparent N recovery is about 75 %. Figure 7.3b shows that N uptake without fertilizer application was considerably higher at 'De Marke' (238 and 193 kg in 1990 and 1992, respectively) and the apparent N recovery was lower (0.47 and 0.66 in 1990 and 1992, respectively). The data for normal practice in the years 1992 and 1993 show N uptakes of 176 and 204 at N application rates of 37 and 108 kg, respectively. Hence, on those fields and in those years N uptake without fertilizer application was lower than in the experiments. In the experiments, apparent N recovery increased with increasing N application. In 1990 the highest recovery was attained at an application of 75 kg, i.e., 74 %, and in 1992 at an application of 150 kg N, i.e. 71 %. This exceptional response is difficult to explain. It is very difficult to estimate the apparent N recovery based on data collected at 'De Marke'. As the apparent N recovery in the TCG for fodder beet is fairly close to the maximum realized in the experiments, it was not changed. An N uptake of 150 kg without fertilizer application seems reasonable when considering the data from fields under normal practice.

Maize and fodder beet are cultivated in rotation with grass. After three years, grass is ploughed in and beet is cultivated. Subsequently, maize is grown either two years on land close to the farm house or four years on land farther away. In the model, the average was set at a 3:1 rotation of maize and fodder beet. After breaking up grassland, additional N becomes available from the root and stubble biomass to subsequent crops. This has been estimated at 80 kg N in the first year, 40 kg in the second year, 30 kg in the third year and 20 kg in the fourth year of the rotation (Biewinga et al., 1992). This N effect after breaking up grassland is accounted for in the TCG models in the N uptake without fertilizer application.

Grazing and feeding losses at 'De Marke' are low due to rotational grazing of 2 days per field and adequate management. The losses referred to by Biewinga et al. (1992) were included in the models.

Two types of concentrates were used, a standard one and a protein-rich one. The standard one has a feeding value and nutrient content similar to concentrate type 2 (Chapter 5, Appendix B), while the protein-rich type is closest to type 5. The original feeding values in the model were replaced by the exact feeding values as reported (Meijer et al., 1994). It was assumed that the ammonia emission factors as described in Appendix B for low-emission constructions apply to 'De Marke', as no measured data are available.

7.3. Comparison of calculated and observed farm performance

The production techniques in the Dairy Farming Model were fixed at those currently practised at 'De Marke'. This enabled simulation of farm performance under the current farm lay-out and management.

7.3.1. Dairy farming at 'De Marke' according to the Dairy Farming Model

Six goals were optimised: milk production, labour income, nitrate leaching, ammonia volatilization, and P and N surplus (Table 7.1). The only restriction imposed in this optimization cycle was an annual milk production of at least 12 t ha^{-1}.

Maximum milk production is 13.5 t, maximum labour income Dfl 1 960, minimum nitrate leaching 32 kg N, minimum ammonia volatilization 21 kg N, minimum P surplus 0.5 kg and minimum N surplus 159 kg. The target values for nitrate leaching and ammonia volatilization of 34 and 30 kg N, respectively, are met in all cases. However, the target value for P surplus of 0.5 kg is only met when the P surplus is minimized. The target N surplus of 128 kg, as set for 'De Marke', cannot be reached by the model for this dairy farming system.

Table 7.1 Best extreme values of the goals: milk production, labour income, NO_3 leaching, NH_3 volatilization, N surplus and P surplus (**bold**) and associated values of the other goals (in the rows) for 'De Marke' with a minimum milk production of 12 t ha^{-1} yr^{-1}.

Goal	Milk production kg	Labour income Dfl	NO_3 leaching kg N	NH_3 volatilization kg N	P surplus kg P	N surplus kg N
Milk production	**13 460**	1 735	33	25	7.1	192
Labour income	13 050	**1 960**	33	25	2.9	181
NO_3 leaching	12 000	1 690	**32**	26	1.1	170
NH_3 volatilization	12 000	1 385	33	**21**	6.2	181
P surplus	12 000	1 740	32	26	**0.5**	175
N surplus	12 000	1 450	32	22	2.2	**159**

Table 7.2 Best extreme values of the goals milk production, labour income, NO_3 leaching, NH_3 volatilization, N surplus and P surplus (**bold**) and associated values of the other goals (rows) for the situation at 'De Marke'. Restrictions have been imposed on milk production, nitrate leaching, ammonia volatilization and P surplus.

Goal	Milk production kg (≥ 12 000)	Labour income Dfl	NO_3 leaching kg N (≤ 34)	NH_3 volatilization kg N (≤ 30)	P surplus kg P (≤ 0.5)	N surplus kg N
Milk production	**12 010**	1 750	32	26	0.5	174
Labour income	12 010	**1 770**	32	25	0.5	173
NO_3 leaching	12 000	1 755	**32**	25	0.5	175
NH_3 volatilization	12 000	1 755	32	**25**	0.5	175
P surplus	12 000	1 725	32	27	**0.5**	176
N surplus	12 000	1 765	32	25	0.5	**174**

These results show that, according to the model, the dairy farming system implemented at 'De Marke' is close to achieving the target values for N and P emissions set in advance.

In the next iteration restrictions were imposed on P surplus, nitrate leaching and ammonia volatilization of 0.5 kg P, 34 and 30 kg N, respectively. Table 7.2 gives the best extreme value for each goal and the associated values of the other goals with these restrictions implemented.

Maximum milk production is 12.0 t, maximum labour income Dfl 1 770, minimum nitrate leaching 32 kg N, minimum ammonia volatilization 25 kg N, minimum P surplus 0.5 kg and minimum N surplus 174 kg. Table 7.2 shows that the solution area is reduced compared to the first iteration, as the difference between the lowest and the highest value of each of the goals has decreased. However, this is not surprising when simulating a system fixed in advance. The restriction on P surplus is limiting the best extreme values of all the goals and those on nitrate leaching and ammonia volatilization limit none of them.

The farming system selected under maximum labour income is briefly discussed (Table 7.3), as, once the environmental requirements are met, the main goal for 'De Marke' is maximum labour income. Maximizing labour income results in a nitrate leaching loss of 32 kg N and an ammonia volatilization of 25 kg N. Both, nitrate leaching and ammonia volatilization are below their target values of 34 and 30 kg N, respectively, and hence, have no shadow price. P surplus has a shadow price of Dfl 565 per kg and is severely limiting on income.

Table 7.3 Characteristics of the dairy farming system at 'De Marke' as simulated by the model under maximization of labour income. The restrictions imposed are: Milk production > 12 t, NO_3 leaching < 34 kg N, ammonia volatilization < 30 kg N and P surplus < 0.5 kg. Most figures apply to an average ha farm land. Only rows marked by '*' are expressed per ha of the specific crop.

Characteristic		Unit	Value
Labour income		Dfl	**1 770**
Nitrate leaching		kg N	32
Ammonia volatilization		kg N	25
P surplus		kg	0.5
Milk production		kg	12 010
N surplus		kg	174
Accumulation + denitrification		kg N	116
Grass fresh (area)		%	44
N application rate*		kg	280
Artificial fertilizer*		kg	200
Grazing system	cows		day grazing+maize
	yearlings		day+night grazing
	calves		zero grazing-maize
Grass conserved (area)		%	16
N application rate*		kg	280
Artificial fertilizer*		kg	210
Product: wilted silage (area)		%	16
Maize (area)		%	30
N application slurry*		kg	133
Artificial fertilizer*		kg	0
Slurry placement			broadcast
Catch crop			+
Maize silage (area)		%	23
Ground ear silage (area)		%	7
Irrigated (area)		%	0
Fodder beet (area)		%	10
N application slurry*		kg	98
Artificial fertilizer*		kg	0
Slurry placement			broadcast
Stocking rate		cows	1.41
Milk production per cow		kg	8 500
Herbage supply level			1.0
Concentrates	purchased	kg	1 670
	produced on-farm	kg	1 200
Concentrates per cow		kg	2 035
Stable + slurry storage			low-emission
Labour input		h	53
N fertilizer		kg	106
P fertilizer		kg	0.0
Income/t milk		Dfl	147
N input:N output		-	2.5

The area under grassland is 60 % of the total. About 25 % is ensiled for feeding in winter. Yearlings are kept under day-and-night grazing and calves under zero grazing. Maize is cultivated on 30 % of the area and receives 133 kg N in slurry, which is equivalent to an inorganic N application of 78 kg. About 75 % of the maize area is ensiled as whole plant maize silage and 25 % as ground ear silage. Fodder beet is cultivated on 10 % of the area and receives 98 kg N in slurry, which is equivalent to 60 kg inorganic N. The stocking rate is 1.41 cows per ha. Herbage supply level is 1.0. The amount of concentrates purchased is 1 670 kg ha^{-1} and the amount of ground ear silage and fodder beet is 1 200 kg ha^{-1}. About 40 % of the concentrates used is produced on the farm itself. Concentrate use per cow is 2 035 kg. At 'De Marke' this was 2 070 kg in 1994 (Meijer et al., 1994), of which 47 % was produced on-farm (De Vries, 1995). N fertilizer input averages 106 kg and no P fertilizer was purchased.

7.3.2. N balance of the farm

The calculated N balance was compared with data for 'De Marke' for 1993/94 (De Vries, 1995) and 1994/95 (Aarts, in prep.), because in preceding years only part of the land had been used and additional roughage was purchased. Table 7.4 shows that the calculated N inputs are 13 kg ha^{-1} higher than achieved on 'De Marke' in 1993/94 and 35 kg lower than achieved in 1994/95. N outputs are 20 and 15 kg higher than calculated, respectively. N input with fertilizer and clover was 65 kg in 1993/94 and 101 kg in 1994/95, while the calculated N input with fertilizer is 106 kg. In the model, purchase of roughage is not permitted, as all roughage has to be produced on the farm. This is also the intention at on 'De Marke', but crop yields have been too low. Hence, roughage from storage was used in the preceding year and a small amount was purchased. In the annual N balance, this is represented by inputs of 37 and 11 kg N for 1993/94 and 1994/95, respectively. N losses associated with the production of this roughage have either been accounted for in the N balance of the preceding year or the roughage was purchased and the losses were attributed to the producer. Roughage can not be produced with 100 % N use efficiency, implying that N inputs are higher when producing the feed than when purchasing it. Calculated N input with concentrates is 18 and 25 kg higher than that realized at 'De Marke' in the given two years, as a larger proportion of the concentrates was purchased in the model. More protein-rich, and P-rich concentrates also are purchased to meet the P requirements of the cattle. In the model calculations, about 600 kg ha^{-1} of fodder beet are sold, containing 4 kg N. At 'De Marke' 8 kg N was sold in fodder beet and an amount of slurry equivalent to 11 kg N ha^{-1}

Table 7.4 N balance of the farm (kg ha^{-1}) according to data collected on 'De Marke' for 1993/94 and 1994/95 and to the Dairy Farming Model.

Input	'De Marke'		Model	Output	'De Marke'		Model
	93/94	94/95			93/94	94/95	
N deposition	49	49	45	Milk	65	64	64
Concentrates	80	73	98	Meat	11	9	7
N fertilizer	53	96	106	Roughage	8	17	4
N fixed clover	12	5	0	Slurry	11	0	0
Roughage	37	11	0				
Slurry	0	50					
Sundries	5	0	0				
Total	236	284	249	Total	95	90	75
				Surplus	141	194	174

was not applied but stored in 1993/94. In 1994/95 roughage containing 17 kg N was stored and 50 kg N was applied with slurry stored in previous years. The restrictions that all slurry has to be applied and no roughage can be purchased are compulsory in the model, but on a farm balancing between years is possible. The calculated N surplus is 174 kg, of which 32 kg N has been leached, 25 kg volatilized and 117 kg accumulated in the soil or denitrified. In 1993/94, N surplus at 'De Marke' was 141 kg, of which 50 kg was leached, 24 kg volatilized and 40 kg accumulated or denitrified. Another 27 kg N was lost from roughage. This may be due to conservation losses, as well as measurement inaccuracies, as it was calculated from the change in fodder reserves and the amount of fodder fed to cattle. In 1994/95, N surplus was 194 kg, of which about 50 kg was leached (estimated by Aarts, in prep), 25 kg volatilized and 133 kg accumulated or denitrified. About 14 kg accumulated in roughage, again calculated from the change in fodder reserves and fodder fed to cattle. The difference between accumulation + denitrification between the two years is very large, i.e. 93 kg N, while nitrate leaching, ammonia volatilization and total N output in products were of the same order of magnitude. Hence, in some years substantially more N inputs seem to be required to attain a certain output, while N losses by volatilization and leaching are similar. One reason may be that inaccuracies in the estimation and measurement of slurry and roughage reserves and ammonia losses accumulate in the N surplus, especially in accumulation + denitrification. It would be worthwhile to analyse the underlying processes of this large annual variation. At present, no additional data are available for 1994/95. It should be noted that model results refer to the average situation and the data from 'De Marke' refer to two years only. For a good comparison, data over a longer period are necessary.

7.3.3. Ration of the dairy cows

In Table 7.5 the rations of the dairy cows in summer and winter are compared according to data collected at 'De Marke' (Meijer et al., 1994) and the model.
At 'De Marke', feed intake in winter is higher than in summer. In winter the cows were fed 8 -10 % above the energy standard. Roughage intake, especially was higher than expected. Actual grass intake for the summer period was estimated by assuming energy requirements were just met. Calculated average daily feed intake over the year is 1.5 kg d^{-1} less than realized. Calculated grass intake is 0.7 kg d^{-1} higher and maize intake is 1.2 kg lower than realized in the period 1992-1994. Calculated concentrate intake, of which 3.0 kg are fodder beets, is 1.3 kg d^{-1} lower. Distribution of feed intake over summer and winter differs considerably, even when feeding above the standard is taken into account. This is due to the fact that calving is spread over the year at 'De Marke', while the model refers to a herd calving at the 1st February. The latter results in higher feed requirements in summer (Chapter 2) and lower in winter.

7.3.4. Nitrate leaching

The nitrate concentration in the soil solution at 1 m depth has been monitored since 1991 at 6 locations and nitrate leaching has been calculated (Hack-ten Broeke & De Groot, 1995; Table 7.6). These locations cover all rotations for a relatively wet and a relatively dry situation (Biewinga et al., 1992).

Table 7.5 Daily ration of dairy cows (kg dry matter cow^{-1}) according to data collected at 'De Marke' in 1992 and 1993 and according to the model.

	'De Marke'			Model		
Feed	summer	winter	average	summer	winter	average
Grass	8.1	7.9	8.0	12.3	5.0	8.7
Beet leaves	0.3		0.1		1.0	0.5
Maize silage	5.5	5.5	5.5	6.0	2.6	4.3
Concentrates	5.2	6.7	5.9	1.2	8.1	4.6
Total	19.1	20.1	19.5	19.5	16.6	18.1

Table 7.6 Nitrate leaching losses in kg N ha^{-1} in relation to rotation and rainfall at 6 locations on 'De Marke' over 3 hydrological years (1 April - 1 April).

	'91/92	'92/93	'93/94
Rainfall		737 mm	1089 mm
Cropping sequence 1991-1993			
Fodder beet-maize-maize		1.6	61.5
Permanent grassland	31.7	49.9	121.5
Grass-grass-fodder beet	7.1	13.9	43.8
Permanent grassland	2.0	15.8	35.8
Grass-fodder beet-maize	9.8	8.9	67.9
Maize-maize-maize	78.6	39.2	33.2

Source : Hack-ten Broeke & De Groot, 1995

Table 7.6 shows large fluctuations in nitrate leaching losses. High nitrate leaching losses could be an indication of leaching during the growing season.
The TCG models for maize and fodder beets calculated an average annual nitrate leaching loss of 48 kg N ha^{-1} from the rotation of 1 year fodder beet and 3 years maize. The average nitrate leaching from grassland as calculated with GRASMOD for the situation at 'De Marke' is 30 kg N ha^{-1}. This value is somewhat higher than those measured in the first two years and lower than in the last year. In general, the measured and calculated values are of the same order of magnitude.
Average nitrate concentration in the upper metre of the ground-water was also measured: 187 mg l^{-1} in 1990, 115 in 1992 and 59 in 1993/94 (Boumans & Fraters, 1995). This reduction is at least partly the result of measures to reduce N losses. However, the low value in 1993/94, just above the EU drinking water norm, was associated with a high rainfall surplus and a high ground-water table, resulting in a higher denitrification rate and dilution of nitrate. The concentration of 59 mm in 1993/94 was equivalent to a leaching loss of 60 kg N ha^{-1} yr^{-1}, i.e. 10 kg above the value reported by Aarts (1994b). Actual rainfall surplus strongly affects the permitted leaching loss in kg N ha^{-1}, as the norm is expressed in mg NO_3 per litre. The measurements in the soil solution and in the upper metre of the ground-water do not fully comply. This may be due to different methods and the time lag between the measurements. Nitrate transport rate in the soil is 1 m per year on average and the ground water table is rather deep at 'De Marke'.

Table 7.7 Ammonia emission (kg N ha^{-1}) as estimated for 'De Marke' for 1992/93 and according to the model.

	'De Marke'	Model
Stable + storage	13	15
Grazing	6	5
Slurry application	3	5
Total farm	21	25

7.3.5. Ammonia volatilization

Ammonia volatilization on 'De Marke' is not actually measured, but was calculated based on several assumptions based on the specific situation (Middelkoop, 1994). Ammonia volatilization from stable and storage in winter and summer is estimated at 6.6 and 6.1 % of the N excreted, respectively. In the model, these values are 6.6 and 9.3 % (Appendix B). For 'De Marke' it is assumed that ammonia emission under grazing is 5 % of the N excreted. In the model this is 6 %. Although based on different sources, the assumptions on ammonia emission for the farm and in the model are comparable resulting in similar overall results (Table 7.7).

7.3.6. P balance

The P surplus attained at 'De Marke' was 6 kg ha^{-1} in 1993/94 (De Vries, 1995), which was the first year the farm functioned with all land in use. Part of the fodder beet produced had to be sold. More than 4 kg fodder beet in the ration resulted in lower milk production and health problems. Hence, P input with concentrates was higher than if fodder beet could have been fed. Due to the large area under maize, which has a low P concentration, P inputs with concentrates are necessarily high. According to the model, the target P surplus of 0.5 kg can be achieved. The P balance realized at 'De Marke' and that calculated by the model are presented in Table 7.8.

The calculated P input with concentrates is about 1 kg lower than that realized, no additional P fertilizer is required and no roughage or slurry is purchased. At 'De Marke' previously stored roughage and slurry, containing 2 and 1 kg P, respectively, were used, and hence, considered inputs.

In reality, in most years crop production is insufficient to avoid roughage purchases or the use of stored reserves. According to the model, it is possible to rely on farm-produced roughage only.

Table 7.8 P balance (kg ha^{-1}) according to data collected at 'De Marke' for 1993/94 and to the model

Input	'De Marke'	Model	Output	'De Marke'	Model
P deposition	1	0.9	Milk	11	10.8
Concentrates	15	13.8	Meat	3	2.2
P fertilizer	2	0.0	Roughage	1	1.2
Slurry	1	0.0			
Roughage	2	0.0			
Total	21	14.7	Total	15	14.2
			Surplus	6	0.5

In general, the simulated results agree reasonably well with results from 'De Marke'. Hence, the dairy farming system at 'De Marke' forms an element in the total solution area. This offers an opportunity to evaluate that system and the scope for further improvements.

7.4. Optimization of dairy farming at 'De Marke'

In the preceding section it was shown that the dairy farming system implemented at 'De Marke' can be simulated using the models developed in this study, provided the input/output relationships are quantified on the basis of actual information.

Subsequently, dairy farming was optimized according to N and P policy objectives for the year 2000 and a target milk production of at least 12 t ha^{-1}, to establish the opportunities for further development of dairy farming under the prevailing conditions at 'De Marke'. The whole range of possible production techniques, as described in Tables 2.1 and 4.1, was quantified on the basis of actual input/output relations. The only difference compared with Table 2.1 is the milk production level, which was set at 7 500, 8 500 and 9 500 kg cow^{-1} yr^{-1} to cover a range around the milk production level reached at 'De Marke'. For maize S=1 is used for the current production level of 10.5 t, i.e. the production level used for simulation of the dairy system at 'De Marke', S=2 is used for a maize production of 11.8 t, which can be attained under irrigation (Section 7.2) and S=3 is not used. Fodder beets are not irrigated and hence, the same production level as indicated in the simulation of the current dairy farming system applies.

Table 7.9 The best extreme values of six goals optimized (**bold**) and associated values of the other goal variables with no restrictions for the situation at 'De Marke'.

Goal	Milk prod. kg	Lab. income Dfl	NO_3 kg N	NH_3 kg N	P surplus kg P	N surplus kg N
Milk prod.	**25 010**	6 340	61	74	19.0	377
Lab. inc.	24 040	**7 010**	69	74	8.7	366
NO_3	0	-2 805	**7**	0	17.3	145
NH_3	0	-4 020	78	**0**	25.3	122
P surplus	0	-2 400	7	0	**0.0**	31
N surplus	0	-4 230	86	0	0.0	**0**

7.4.1. The solution area for the situation at 'De Marke'

Six goals were optimized: milk production, labour income, nitrate leaching, ammonia volatilization, P surplus and N surplus.

The results of the first optimization round, in which the best extreme values without any restrictions are established, are presented in Table 7.9. Maximum milk production is 25.0 t ha^{-1} and maximum labour income Dfl 7 010. Nitrate leaching can be reduced to 7 kg N and ammonia volatilization to 0. Both P and N surplus can be reduced to 0. These values define the outer boundaries of the solution area. However, as explained in Subsection 6.1.1, not all these results are realistic. Minimization of N and P losses results in a large negative labour income and no milk production at all.

In subsequent optimization cycles, the restrictions on production and emission goals have been tightened. In successive optimization rounds, milk production was set at at least 12 t, nitrate leaching was limited to 34 kg N, ammonia volatilization was limited to 30 kg N and P surplus was limited to 0.5 kg P. In addition to these restrictions, at 'De Marke' a maximum N surplus of 128 kg has been defined, based on 34 kg NO_3-N leaching, 44 kg NH_3-N volatilization, 3 kg N_2O-N loss, 47 kg N denitrification and no accumulation. Hence, the restriction on N surplus is an indirect goal derived from other goals. N surplus was optimized to get an indication of its magnitude, but no restriction was defined. The assumptions on denitrification and accumulation are rather precarious, as these processes are very difficult to measure in the field (Goossensen & Meeuwissen, 1990; Jarvis et al., 1991; Hassink et al. 1994). Moreover, in the model, accumulation is a balancing component. The calculated accumulation is

Table 7.10 The best extreme values of six goals optimized (**bold**) and associated values of the other goal variables with restrictions on milk production, nitrate leaching, ammonia volatilization and P surplus (in brackets) for 'De Marke'.

Goal	Milk prod. kg (≥ 12 000)	Lab. inc. Dfl	NO_3 kg N (≤ 34)	NH_3 kg N (≤ 30)	P surplus kg P (≤ 0.5)	N surplus kg N
Milk prod.	**17 660**	3 700	34	30	0.5	225
Lab. inc.	15 350	**4 380**	34	30	0.5	269
NO_3	12 000	1 650	**13**	22	0.5	165
NH_3	12 000	2 145	34	**17**	0.5	160
P surplus	15 180	4 210	34	30	**0.0**	269
N surplus	12 000	1 120	24	20	0.5	**94**

not based on experimental data or theoretical assumptions. It represents the gap after accounting for all other processes with respect to N fluxes. Hence, this value accumulates all uncertainties in the other process rates.

The maximum annual milk production is 17.7 t ha^{-1}, maximum labour income Dfl 4 380, minimum nitrate leaching 13 kg N and minimum ammonia volatilization 17 kg N (Table 7.10). The P surplus can be reduced to 0 and the N surplus to 94 kg.

The dairy farming systems selected through optimization of the various goals differ considerably (Table 2 in Appendix D). Figure 7.4a shows the land use selected for each of the goals. When maximizing milk production, maize is cultivated on almost 20 % of the area, grass for conservation on 30 % and grass for fresh consumption in summer on 50 %. Dairy cows and yearlings are kept in a zero grazing system and calves in a day-and-night grazing system. In summer, cows are supplemented with maize. When maximizing labour income, only grass is grown, of which about 25 % is conserved for feeding in winter. Cows are kept under day-and-night grazing and the young stock under zero grazing. When minimizing nitrate leaching, again all land is under grass. About 30 % of the area is used for feeding dairy cows and young stock in a zero grazing system and 25 % for day-and-night grazing by dairy cows. About 20 % of the area is used for conservation as wilted silage and 25 % for artificial drying. The artificially dried grass is not fed to the cattle, but sold and a mixture of 4 types of concentrates is purchased instead, because this more closely meets the feed requirements of the cattle. When minimizing volatilization losses, about 15 % of

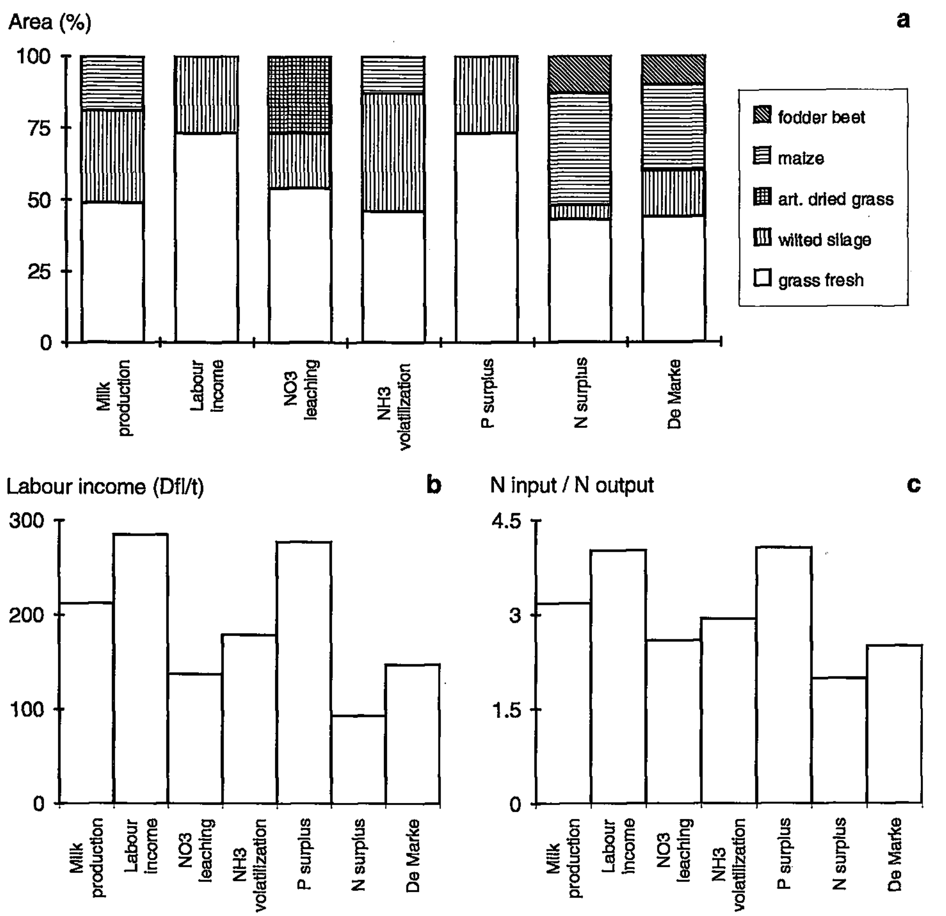

Figure 7.4 Land use (a), labour income (b) and N input:output ratio (c) when optimizing each of the six goals with restrictions on milk production (≥ 12 t), nitrate leaching (≤ 34 kg N), ammonia volatilization (≤ 30 kg N) and P surplus (≤ 0.5 kg P) and the values attained at 'De Marke'.

the area is cultivated with maize and 45 % of the area is used for the production of fresh grass for the cows kept indoors and for day-and-night grazing by young stock. In summer, cows are supplemented with maize. About 40 % of the area is used for conserving grass. When minimizing P surplus, the dairy farming system is very similar to that when maximizing labour income. The main difference being that a larger part of the purchased concentrates has a low P concentration. These concentrates are more expensive and hence, labour income is somewhat lower. When minimizing N surplus, 40 % of the area is cultivated with maize, 45 % is used for zero grazing and 5 % for conservation of grass. About 10 % of the area is cultivated with fodder beets. In summer, cows are supplemented with maize.

Labour income per tonne of milk is highest when maximizing labour income (Figure 7.4b). Maximizing milk production results in a 2.3 t higher value than attained under labour income (Table 7.10), labour income per tonne of milk is substantially lower. It is lowest at the minimum N surplus. Figure 7.4c shows the required N input per kg N incorporated in milk, meat and sold roughage. At maximum labour income and minimum P surplus, N inputs required to produce 1 kg N output are highest. At a minimum N surplus the N input:output ratio is lowest. Under minimization of N losses, i.e. minimum nitrate leaching, ammonia volatilization and N surplus, part of the roughage produced is sold, which results in a high N output and hence, a favourable N input:output ratio.
This analysis shows that for the situation at 'De Marke' a wide range of dairy farming systems is possible, all of which meet the N and P policy objectives for the year 2000 and the production target of at least 12 t ha^{-1}. The choice depends on the relative importance attached to the various objectives.

7.4.2. The dairy farming system for 'De Marke' under maximization of labour income

The main goal at 'De Marke' is to meet the environmental targets for N and P as defined for the year 2000. Once these have been met, the highest possible labour income is aimed at. Hence, the dairy farming system when maximizing labour income will be discussed in more detail (Table 7.11, column A). Nitrate leaching, ammonia volatilization and P surplus are all at their limiting value. The shadow price for nitrate leaching is Dfl 26 kg^{-1} N, for ammonia volatilization Dfl 32 kg^{-1} N and for P surplus Dfl 333 kg^{-1} P. Hence, the restriction on P surplus is the most constraining factor. Milk production is 15.4 t ha^{-1}. N surplus is 269 kg of which 205 kg accumulates in the soil or denitrifies. N mineralization on the soil at 'De Marke' is very low (52 kg; Section 7.2). Hence, temporarily, a large accumulation of N can be expected. In the course of time accumulation will decrease to zero, when equilibrium is reached. The measurements and calculations for 'De Marke' have not confirmed large accumulation. However, this may also be due to the large proportion of grassland in rotation. In 1993/94 accumulation and denitrification were estimated at 36 kg N only (Aarts, 1994a). This aspect requires more attention in future research.
The area used for feeding cattle in summer is 73 % with an average N application rate of 270 kg. Cows are grazing day and night and N application rate to this grassland is 250 kg. Young stock is kept under zero grazing for which 6 % of the area is used with an N application rate of 400 kg. All grassland used for feeding in summer is cut at least once a year and on 13 % of the area, all

Table 7.11 Characteristics of the dairy farming system selected by the model for 'De Marke' under maximization of labour income. In column A the restrictions imposed are: Milk production > 12 t ha-1, NO_3 leaching < 34 kg N, NH_3 volatilization < 30 kg N and P surplus < 0.5 kg. In column B a restriction on N surplus of 128 kg is added. Most figures apply to an average ha farm land. Only rows marked by '*' are expressed per ha of the specific crop.

Characteristic		Unit	Value	
			A	B
Labour income		Dfl	**4380**	**2600**
Nitrate leaching		kg N	34	34
Ammonia volatilization		kg N	30	22
P surplus		kg	0.5	0.5
Milk production		kg	15350	12125
N surplus		kg	269	128
Accum. + denitrification		kg N	205	72
Grass fresh (area)		%	73	47
N application rate*		kg	270(250-400)	230(100-250)
Artificial fertilizer*		kg	205	130
Grazing system	cows		day+night grazing	day grazing+maize
	yearlings		zero grazing-maize	zero grazing-maize
	calves		zero grazing -maize	zero grazing-maize
Grass conserved (area)		%	27	6
N application rate*		kg	380(250-450)	210(100-250)
Artificial fertilizer*		kg	240	75
Product: wilted silage (area)		%	27	6
Maize (area)		%	0	48
N application slurry*		kg		103
Artificial fertilizer*		kg		0
Slurry placement				row
Catch crop				+/-
Maize silage (area)		%		44
Ground ear silage (area)		%		4
Irrigated (area)		%		31
Stocking rate		cows	1.62	1.28
Milk production per cow		kg	9500	9500
Herbage supply level			1.00	1.00
Concentratespurchased		kg	3640	1485
produced on-farm		kg	0	245
Concentrates per cow		kg	2250	1352
Stable + slurry storage			low-emission	low-emission
Labour input		h	62	46
N fertilizer		kg	214	65
P fertilizer		kg	0.0	0.0
Income/t milk		Dlfl	285	214
N input:N output		-	4.0	2.8

grass is conserved for winter feeding, receiving 450 kg N. In total 27 % of the area is used for grass conserved for winter feeding. Herbage is cut at a yield of 4 t dry matter ha^{-1}. No maize or fodder beets are cultivated.
The amount of N available from slurry is 148 kg, which is applied on grassland by both deep injection and injection with open slits, in addition to N application with artificial N fertilizer. The stocking rate is 1.62 cows ha^{-1} and milk production per cow is 9 500 kg. The herbage supply level is 1.0. All concentrates are purchased and the amount fed per cow is 2 250 kg yr^{-1}. About 41 % of the concentrates is ground ear silage, which has a low N and P content, 40 % is type 6 with a standard N and a low P content, 16 % is type 5 with a high N and high P content and 3 % is standard concentrate. Average N and P contents of the concentrates are 27.3 and 4.4 g kg^{-1}, respectively. The average daily ration of the dairy cows in winter consists of 9.0 kg concentrates and 8.9 kg DM of wilted silage.
Low-emission stable and slurry storage constructions are used. Labour input is 62 h ha^{-1}. Total artificial N fertilizer input is 214 kg and no additional P fertilizer is purchased. Labour income per tonne of milk is Dfl 285. For each kg N incorporated in milk and liveweight gain, an external input of 4.0 kg N is required.
It has been assumed that all grassland is irrigated. This may lead to high labour requirements in dry spells in summer. If a temporary labour shortage occurs, labour should be hired. However, this has not been accounted for separately in the model. Hence, in years that additional labour has to be hired, the labour income of the farmer will be somewhat lower than the calculated labour income. However, the net result will not be influenced. Net result covers the remuneration for management only and costs of both family and hired labour have been subtracted. Net result for the dairy farming system as described above is Dfl 2 470 ha^{-1} yr^{-1}.
The dairy farming system selected by the model differs considerably from that currently practised at 'De Marke'. This is mainly due to the absence of a restriction on N surplus in the model (Subsection 7.5.1). In the selected dairy farming system, cows are kept under day-and-night grazing, which is the cheapest grassland utilization method. If this can be practised without exceeding the nitrate leaching norm, it is preferred over other grassland utilization methods. Under zero grazing by young stock, and cutting for conservation only, N application rates of 400 kg ha^{-1} yr^{-1} are possible. On these fields the nitrate leaching limit is exceeded, but this is compensated by lower leaching losses from other fields. Labour income per tonne of milk is Dfl 285 and the ratio N-input:N-output is 4.0. In the dairy farming system simulated for 'De

Marke' (Section 7.3, Table 7.3) these values are Dfl 150 and 3.4, respectively. However, in reality the N input:output ratio was found to be 2.5 (Table 7.4). Hence, the system currently practised at 'De Marke' uses N more efficiently than those selected by the Dairy Farming Model. In the course of time, however, the N input:output ratio of the dairy farming system selected by the model will decrease, as N supply from soil reserves will increase due to the high N accumulation. Hence, less fertilizer will be required to maintain crop yields.

7.5. Effectiveness of measures to reduce N and P emissions at 'De Marke'

The dairy farming system at 'De Marke' aims at N and P emissions within the norms set for the year 2000. In the initial phase of the farm, this objective has led to a coherent set of measures, with an impact on various parts of the system (Biewinga et al., 1992). In this section the effectiveness of various measures will be evaluated. The measures are expressed in model terms and further optimization rounds were carried out. The dairy farming system under maximum labour income, as described in Subsection 7.4.2 and Table 7.11 Column A, will be used as the reference. This system meets the norms for 2000 and achieves a level of milk production well above 12 t ha^{-1}, the average for sandy soils in the Netherlands.

7.5.1. Restricting N surplus to 128 kg ha^{-1}

In 1993/1994 the ratio N input:output at 'De Marke' was 2.5 (Table 7.4). Considering this input:output ratio and the land use, the dairy farming system at 'De Marke' is closest to those selected for minimum N losses, i.e. minimum nitrate leaching, ammonia volatilization and N surplus (Figure 7.4c). In the initial design of 'De Marke' N surplus was limited to 128 kg (Biewinga et al., 1992). This was not considered in the optimization rounds for reasons explained in Section 7.3. Table 7.10 shows that the N surplus when optimizing the other goals varies between 160 and 269 kg, which is far above the target. If a limit of 128 kg N is set on N surplus, the optimization results are more in agreement with the current system at 'De Marke' (Table 7.11 column B). However, in this system no fodder beets are grown.

Maximum income is Dfl 2 600 and milk production 12.1 t. N application on grassland is about 225 kg, of which about 125 kg is applied as inorganic fertilizer. The area under grassland is reduced drastically when compared to the reference situation. Maize is cultivated on 48 % of the area. Dairy cows are grazing during daytime only and are supplemented with maize during the night. Young stock is kept inside all year round. Concentrate use per cow is

1 350 kg, of which 15 % is ground ear silage produced on-farm. Average N fertilizer input is 65 kg. Labour income per ton milk is Dfl 214 and the ratio N input:output is 2.8. The ration in winter is mainly based on maize silage supplemented with protein-rich concentrates.

Comparison of the production techniques selected with and without a restriction on N surplus, shows that in the first instance production techniques with a lower N fertilizer input and a lower N surplus are selected. N accumulation occurs mainly on grassland. The large accumulation in both situations shows that neither of the systems is in equilibrium in terms of organic N. In the long term, this will lead to higher mineralization rates and, hence, lower fertilizer requirements to attain the same level of grass production. N content of the grass and hence, N excretion in faeces and urine, will remain similar. The increased nitrate leaching associated with higher mineralization rates will at least partly offset lower leaching losses from fertilizer. Utilization of N originating from organic matter is 95 % of that from fertilizer N (Chapter 2). Hence, volatilization and leaching losses will hardly change. If finally, equilibrium is reached, no N accumulation will occur and hence, the N surplus will be lower than in the situations described here. However, that does not imply lower N losses to the environment from the selected system. Assuming denitrification losses for 'De Marke' have been estimated correctly, the restriction on N surplus as defined for 'De Marke' applies to the equilibrium situation. As that equilibrium has most probably not been reached yet, N surplus can be higher than 128 kg without exceeding the nitrate and ammonia emission targets.

It should be noted that in the model N surplus is a mathematical balance term and hence, actual accumulation may be different. The estimates for denitrification in particular are debatable and very uncertain. Compared with the assumption for 'De Marke', denitrification rate in the model is very low. However, this only influences the distribution of N over the balance items denitrification and accumulation.

This analysis shows that a limit on N surplus has a major influence on the system selected under maximum labour income to meet the N and P norms for the year 2000, especially on land use, grassland utilization method, N input:output ratio and labour income.

7.5.2. Restricting P surplus to 0.5 kg ha^{-1}

At 'De Marke' the target P surplus is 0.5 kg. Minimization of the P surplus has shown that it can be reduced to zero (Table 7.10). The acceptable P surplus is still in discussion. The restriction on P surplus was set to 0, 0.5, 1.0, 2.5, 5.0 and

7.5 kg ha^{-1}, respectively and labour income has been maximized. The complete results are presented in Table 3 in Appendix D.

At a permitted P surplus of 7.5 kg, the actual P surplus is 6.3 kg and hence, P is not limiting. For all values for P surplus, only grass is cultivated. Labour income increases with mitigation of the restriction on P (Figure 7.5a). Without P being restrictive, maximum labour income is Dfl 5 265, which is 20 % above the value at a P surplus of 0.5 kg. Milk production is 17.5 t, i.e. 14 % higher. Nitrate and ammonia losses are both at their limiting value independent of P surplus. Cows are outside day and night in summer. At a P surplus above 5 kg, day-and-night grazing is gradually replaced by zero grazing. Under zero grazing there is a higher N application rate and hence, a higher stocking rate, is also possible without exceeding the norms on N losses.

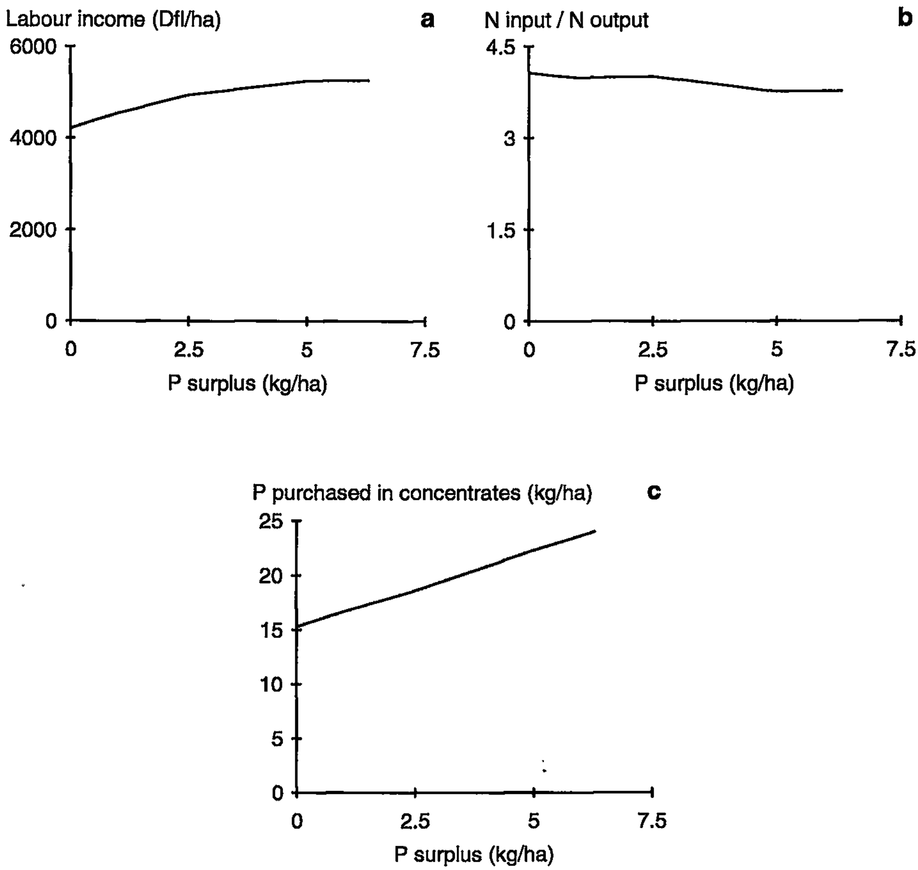

Figure 7.5. The relationship between target P surplus and (a) labour income, (b) N input:output ratio and (c) P in purchased concentrates.

Labour income per tonne milk increases up to a permitted P surplus of 2.5 kg and subsequently slightly decreases. The N input:output ratio is hardly affected by the P surplus (Figure 7.5b). However, in zero grazing systems the N input:output ratio is lower than in a grazing system (Subsection 7.5.4). Hence, at a P surplus above 5 kg, N input:output ratio is lower. Concentrate use increases from 2190 kg per cow at a P surplus of 0 to 2 900 kg when P surplus is not limiting. The amount of P in purchased concentrates increases from 15.3 to 24.0 kg ha^{-1} (Figure 7.5c). Purchase of low-P concentrates is gradually reduced to 0, as this type of concentrate is more expensive. At low P surpluses, the amount of P available in the feed limits the number of cows that can be kept and hence, milk production and labour income. P fertilizer is not purchased in any of the systems.

This analysis shows that limiting P surplus to 0.5 kg reduces labour income by about 20 %. The factor limiting labour income is the amount of P that can be purchased in concentrates and fertilizer.

7.5.3. Production of concentrates on-farm

For 'De Marke' a target of 50 % has been set for the production of concentrates on-farm. However, in none of the optimizations of the six goals is the production of concentrates on-farm selected. Therefore, the influence of increasing the proportion of on-farm produced concentrates from 0 to 95 % was explored, again within the N and P emission norms for 2000. The complete results are given in Table 4 in Appendix D. Figure 7.6a shows that until 75 % production of on-farm produced concentrates is reached, all land remains under grass. Hence, the type of concentrate produced on-farm is artificially dried grass. Above 75 %, maize cultivation comes to the fore, which is partly harvested as ground ear silage. The area used for feeding grass in summer declines from 73 to 45 %. The area used for ensiling grass remains more or less constant over the whole range.

Figure 7.6b shows a decrease in labour income with an increasing proportion of on-farm produced concentrates. The effect on labour income is limited up to 25 %: it decreases from Dfl 4 380 to Dfl 4 285. However, at 50 % it has already decreased to Dfl 3 900. Figure 7.6c shows the effect on milk production, which is slightly higher at 25 % than at 0. When up to 75 % concentrates are produced on-farm, labour income per tonne of milk is hardly influenced, but above that it decreases. The ratio N input:output is 3.9 at 25 % of concentrates produced on-farm. Between 50 and 90 % it is about 4.3. At 95 % it decreases again to 4.0. N inputs in concentrates decrease, but more N fertilizer is required for maximum

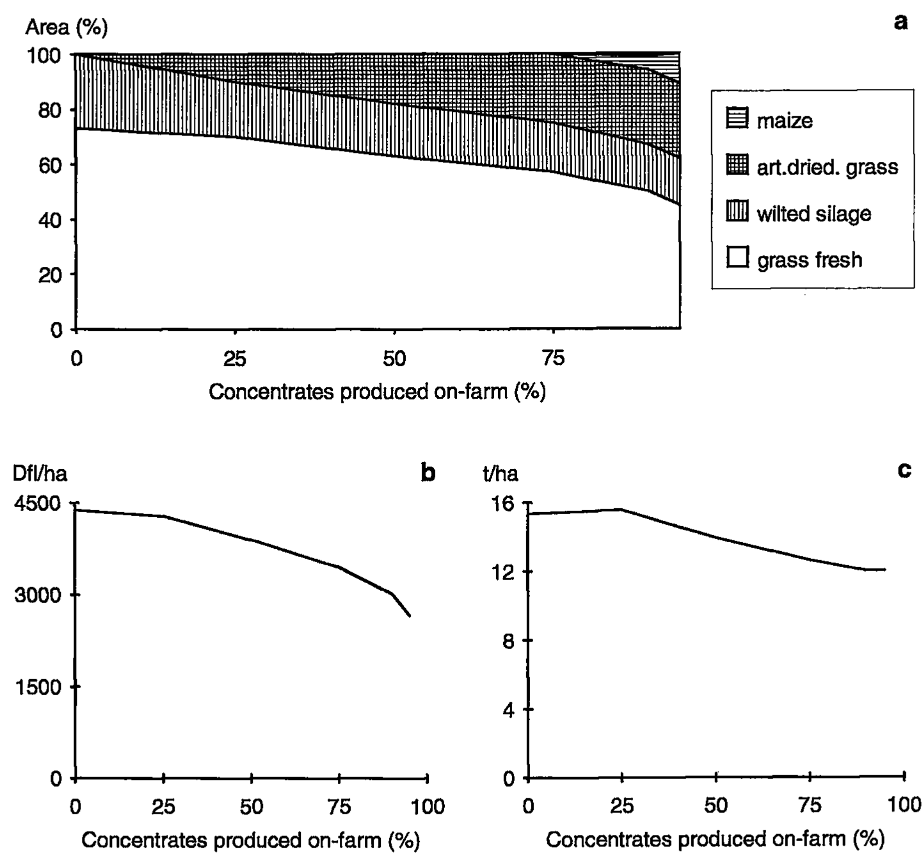

Figure 7.6. The relationship between the proportion of concentrates produced on-farm and (a) land use, (b) labour income and (c) milk production.

income. N output in milk is reduced and the overall result is an higher N input per kg output between 50 and 90 % of on-farm produced concentrates. At 95 % it decreases again (Table 4 in Appendix D).

Although N surplus decreases from 269 kg at 0 % to 212 kg at 95 % of concentrates produced on-farm, N losses by volatilization are reduced by only 3 kg and by leaching they remain similar. The grassland utilization method for dairy cows is day-and-night grazing with up to 75 % on-farm concentrate production. At 90 % part of the herd is kept under zero grazing with maize supplementation, which increases at 95 % of on-farm produced concentrates. Young stock is kept under zero grazing in all cases.

This analysis shows that it is more profitable to purchase concentrates than to produce them on-farm. However, with on-farm production of up to 25 % of the total amount used, the adverse effects on labour income and N input:output ratio are limited. There is no effect on N surplus when producing up to 50 % of the concentrates on-farm. Producing a larger proportion of the concentrates on-farm has a small positive effect on N surplus, which is an important goal for 'De Marke'.

7.5.4. Maize cultivation

At maximum labour income within the norms for N and P emission in 2000, no maize is cultivated (Table 7.11), while at 'De Marke' 30 % of the area is cultivated with maize. To evaluate to effect of maize in the system, the land under maize has been increased from 0 to 60 % in steps of 10 %. At 70 % maize, milk production of 12 t can no longer be attained in the model, as the area under grass is insufficient for the ration in summer to be based on grass products. The complete results are presented in Table 5 in Appendix D.

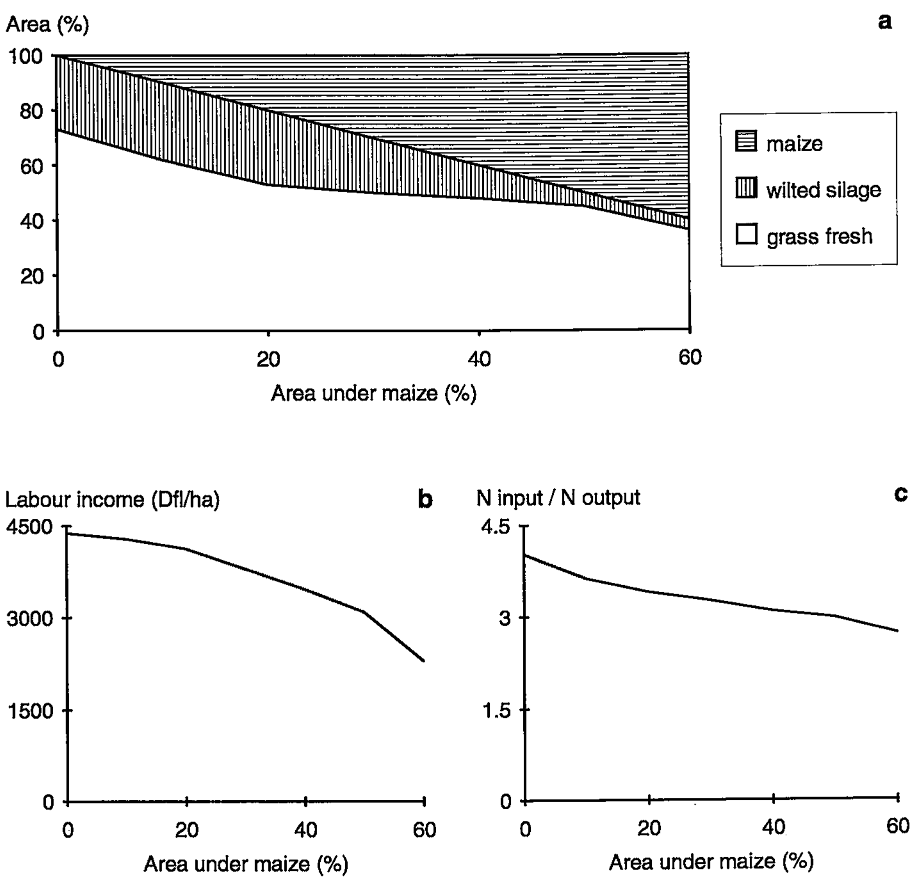

Figure 7.7 The relationship between the proportion of farm land cultivated with maize and (a) land use, (b) labour income and (c) N input:output ratio.

Without any maize cultivation, all land is under grass and 75 % is used for feeding fresh grass in summer (Figure 7.7a). At first, the introduction of maize is mainly at the expense of grass used in summer. The grassland utilization method changes from day-and-night grazing to day grazing with maize supplementation and eventually to zero grazing with maize supplementation.
The introduction of maize leads to only a slight reduction in income until 20 % maize is reached (Figure 7.7b). At 30 %, which is comparable to 'De Marke', income is reduced by 13 %. Milk production first increases slightly, but decreases above a maize proportion of 20 %. Above 20 %, the introduction of maize is mainly at the expense of grass used for conservation. This results in the gradual replacement of wilted silage by maize silage in the winter ration.
Labour income per tonne of milk decreases by about 5 % per 10 % increase in maize area until 50 %, after which labour income decreases by 20 % when the maize area increases to 60 %. At 30 % it is Dfl 246. The ratio N input:output decreases from 4.0 at no maize to 3.3 at 30 % maize and 2.7 at 60 % maize. Hence, N inputs required to incorporate 1 kg N in products decrease. However, N losses due to volatilization and leaching are hardly affected (Table 5, Appendix D). N surplus is drastically reduced from 269 at 0 % maize to 140 kg at 60 % maize. Both slurry and inorganic fertilizer are placed in the row and a catch crop is grown. These measures are necessary to meet the restrictions on nitrate leaching and ammonia volatilization. Ground ear silage is only harvested if 50 % of the area is under maize and even then only a small amount.
This analysis shows that cultivation of maize on up to 20 % of the area has only a small influence on farm labour income and nitrate and ammonia losses. However, income per tonne milk is reduced by 12 % and N input:output ratio is improved by 17 %. Cultivation of maize on a greater part of the area reduces labour income to a larger extent and hardly decreases nitrate and ammonia losses. Hence, the 30 % maize at 'De Marke' results in a reduced labour income and a more favourable N input:ouput ratio. This shows that reducing N surplus was a major consideration in designing the original farm system at 'De Marke'.

7.5.5. Grassland utilization method

At 'De Marke' day grazing with maize supplementation is practised for dairy cows and young stock is kept outside day and night. In the reference system (Table 7.11, column A) dairy cows are outside day and night without maize supplementation and young stock is kept in a zero grazing system. Additional optimizations were carried out to examine the influence of the grassland utilization method. If cows are kept inside all year round, this also applies to

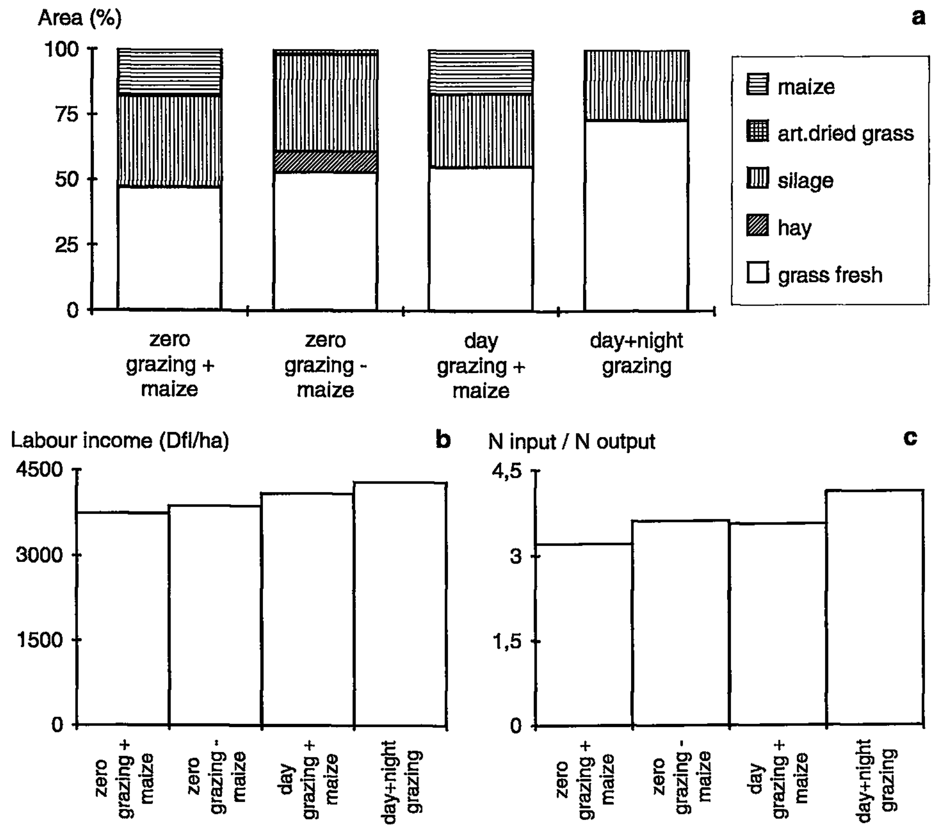

Figure 7.8 The influence of grassland utilization method on (a) land use, (b) labour income and (c) N input:output ratio.

young stock. If cows are outside during at least part of the year, young stock is kept in a day-and-night grazing system. Of course other combinations of grassland utilization methods for dairy cows and young stock can also be applied, as occurs in the reference situation, but this is not essential to the results.

The complete results are presented in Table 6 in Appendix D. Under zero grazing and day grazing, both with maize supplementation, almost 20 % of the area is cultivated with maize (Figure 7.8a). Both slurry and inorganic fertilizer are placed in rows and a catch crop is grown. Maize is only harvested for silage. Under the other dairy farming systems no maize is cultivated. The proportion of the area used for feeding grass in summer varies form 47 % under zero grazing with maize supplementation to 73 % under day-and-night grazing. The fraction of the area used for conservation of herbage as wilted silage varies between

27 and 37 %. Under zero grazing without maize supplementation 2 % of the cut herbage is dried artificially and 8 % is made into hay.
Despite the higher milk production under zero grazing both with and without maize supplementation (Table 6 in Appendix D), labour income is lower than in the grazing systems (Figure 7.8b). Day-and-night grazing results in the lowest milk production and the highest labour income. If dairy cows are grazing day and night and young stock is kept inside, labour income is even slightly higher (Table 7.11). Labour income under zero grazing with maize supplementation is 13 % lower than under day-and-night grazing and milk production is 16 % higher. Labour income per tonne of milk is Dfl 215 and Dfl 285, respectively. N input:output ratio is lower for the systems feeding maize in summer than for the others and lower for the zero grazing systems than for the grazing systems (Figure 7.8c). N application rates are lower in the grazing systems, as the nitrate leaching target has to be met. Total ammonia volatilization and nitrate leaching are hardly affected.
This analysis shows that grassland utilization method influences farm economic performance. Farm labour income is not greatly affected under zero grazing, but labour income per tonne of milk is 20 to 25 % lower. Maize supplementation improves N input:output ratio, as does zero grazing compared to grazing systems. The grassland utilization method at 'De Marke' results in a slightly reduced labour income, i.e. about 5 %, and improved N input:output ratio when compared to the reference system.

7.5.6. Milk production per cow

At 'De Marke' milk production per cow is about 8 500 kg. In the reference system cows producing 9 500 kg are selected. In this subsection, the influence of milk production level per cow is evaluated by setting the milk production level at 7 500, 8 500 or 9 500 kg. The complete results are presented in Table 7 in Appendix D.
The dairy farming systems selected under maximimum labour income for all three milk production levels are basically the same. Cows graze day and night in summer. At the highest milk production level, young stock is kept inside all year round and at the other two levels young stock graze day and night in summer. Figure 7.9a shows that labour income increases substantially with increasing milk production level. Milk production per ha is 13.2, 14.3 and 15.3 t for 7 500, 8 500 and 9 500 kg cows, respectively. Labour income per tonne of milk increases from Dfl 200 to Dfl 285 with increasing milk production (Figure 7.9b). N application rate is hardly influenced. Concentrate use per cow increases with milk

production level per cow, i.e. 1 745, 1 990 and 2 250 kg, respectively. The N input:output ratio decreases with increasing milk production level (Figure 7.9c). This analysis shows that from an economic point of view, it is most profitable to have dairy cows with a high level of milk production. Nitrate and ammonia losses can be kept within the limits defined for the year 2000 and moreover, N use efficiency increases.

In the model the number of young stock kept per cow is similar for all milk production levels, assuming that each cow delivers one calf a year and that veterinary costs are the same. However, cows with a high level of milk production are often more susceptible to disease and have greater fecundity

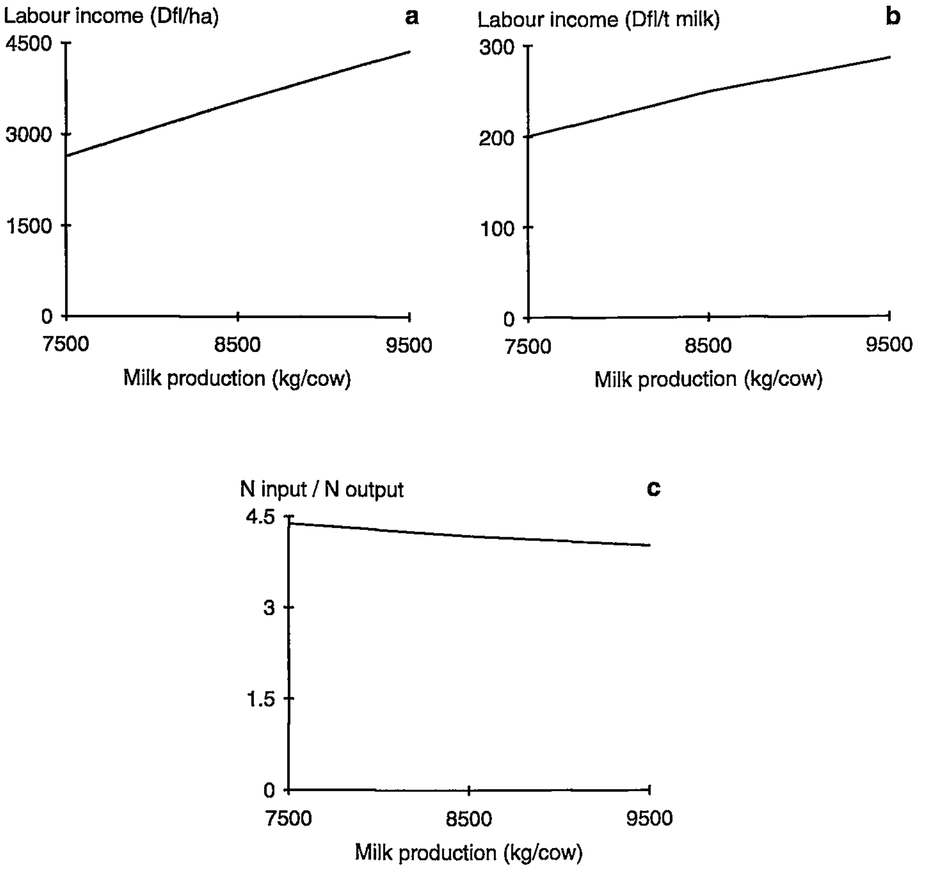

Figure 7.9 The relationship between level of milk production per cow and (a) labour income per ha, (b) labour income per tonne milk and (c) N input:output ratio.

problems. Moreover, the feed requirements and the feed conversion of highly productive cows are issues under discussion. In the model, feed requirements for highly productive cows are based on the feeding standards, which have been based on experiments with cows producing about 6 000 kg milk. There are indications that these standards are not entirely applicable to highly productive cows, which seem to have higher feed requirements than calculated according to the standard (Meijer at al, 1994). These aspects were not taken into account and the optimization results may therefore be too optimistic for highly productive dairy cows. This problem needs more detailed attention in future development of the model and research.

7.5.7. Milk quota

The target for milk production at 'De Marke' is at least 12 t ha^{-1}, i.e. about the average milk quota on sandy soils in the Netherlands. According to the model, milk production at maximum labour income is 15.3 t. In this subsection the influence of milk quota varying from 12 to 15.3 t ha^{-1} is evaluated. The complete results are presented in Table 8 in Appendix D.

Labour income is reduced by 21 % if the milk quota is reduced from 15.3 to 12 t ha^{-1} (Figure 7.10a). At a high milk quota young stock is kept inside all year round to keep as many dairy cows as possible in a day-and night grazing system. At a lower milk quota, this is no longer necessary and young stock is gradually transferred outside in summer. At a milk quota of 12 t, N application on grass fed in summer is 225 kg compared to 270 kg in the reference system. The N input:output ratio increases from 4.0 at a milk quota of 15.3 t to 4.6 at a milk quota of 12 t (Figure 7.10b). This is partly due to the increase in N input:output ratio of the grassland utilization method and partly to the lower output of N in milk and meat. Concentrate use per cow decreases from 2 250 kg at the highest to 1 410 kg at the lowest milk quota (Figure 7.10c). At a lower quota it is no longer necessary to keep all animals in low-emission stable and storage constructions. At a milk quota of 12 t, measures that reduce volatilization losses to a level that can be maintained by keeping 42 % of the dairy cows in low-emission constructions will suffice or, in case of one stable type, reducing ammonia emissions to less than 50 %.

This analysis shows that milk quota have a strong effect on the grassland utilization method, concentrate use and stable and slurry storage type in the optimum dairy farming system. By increasing milk quota both the N input:output ratio and labour income are improved.

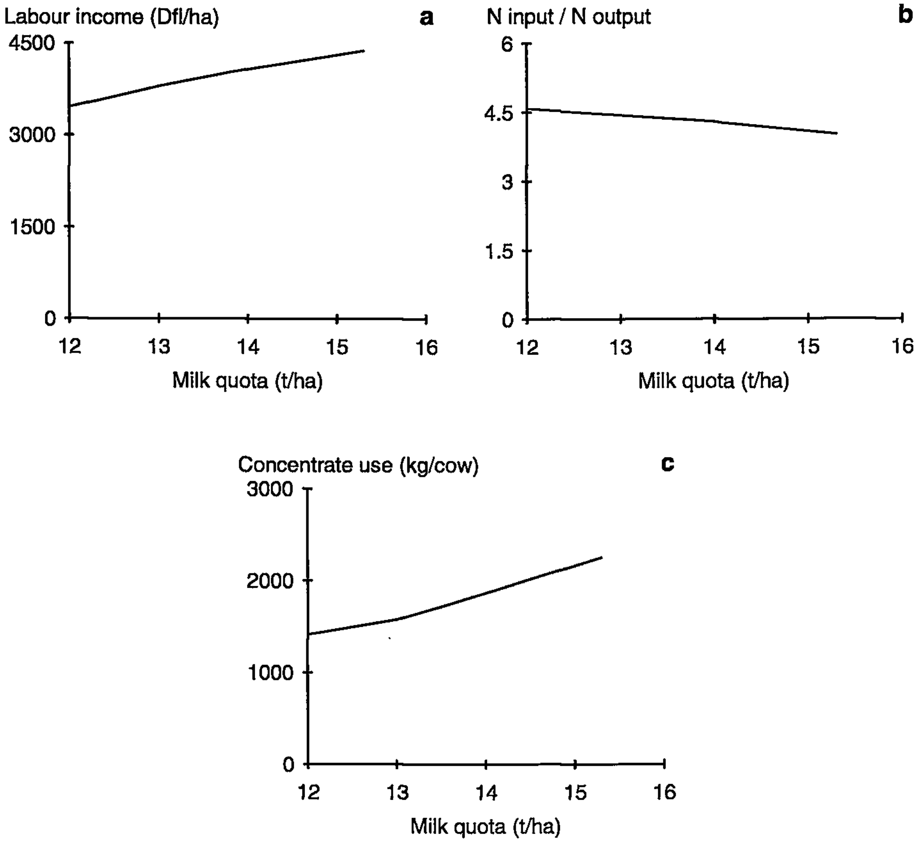

Figure 7.10 The relationship between milk quota and (a) labour income, (b) N input:output ratio and (c) concentrate use.

7.6. Sensitivity of model results with respect to two aspects

The model can be tested on its sensitivity to the parameter values set in this study. However, there are numerous. For 'De Marke' two aspects in particular were notable: the low N mineralization rate under grassland and the reason why fodder beets are hardly ever selected. These two aspects were studied in more detail.

7.6.1. Influence of N mineralization rate under grassland

Potential N mineralization measured by incubation in two fields at 'De Marke' in 1993 was 200 and 380 kg, respectively (Aarts, 1994c). Although under field conditions the mineralization potential may not be realized, part of the N mineralized is incorporated in roots and stubble and recovery of soil mineral N is lower than that of fertilizer N; an N uptake of 56 kg without fertilizer application (Subsection 7.2) is difficult to explain. The effect of a higher N uptake without fertilizer application and a correspondingly higher leaching loss from the soil N pool (Subsection 7.2) was evaluated with the Dairy Farming Model.

The mineralization rate and leaching loss from soil organic N as originally used in GRASMOD, i.e. 150 and 13 kg N, respectively, were applied to the situation at 'De Marke'. The restrictions on milk production, nitrate leaching, ammonia volatilization and P surplus were set at 12 t, 34 kg N, 30 kg N and 0.5 kg P, respectively, and the results have been compared with the reference run (Section 7.5, Table 7.11). The complete results are given in Table 9 in Appendix D.

Maximum labour income is increased by 6 % to Dfl 4 665. Milk production at this income is increased by 1.5 % to 15.6 t. On grassland consumed fresh and the associated area used for conservation, the N application rate is reduced by 100 kg to 170 kg, as less fertilizer is required to attain a similar yield and the leaching loss without fertilizer application is higher. On grassland used for conservation only, N application remains unchanged. A small proportion of the dairy cows (7 %) and all calves are kept under zero grazing instead of day-and-night grazing, as this is associated with lower leaching losses and higher milk production, and a smaller area is required for calves. Part of the ammonia volatilization during grazing is replaced by volatilization during and after slurry application. Ammonia volatilization becomes more limiting and nitrate leaching less limiting on income, i.e. their shadow prices change from Dfl 32 to Dfl 93 and Dfl 26 to Dfl 8 per kg N, respectively. The shadow price of the P surplus is reduced from Dfl 333 to Dfl 315 per kg P. The amount of N imported with concentrates is 7 kg higher. The amount of concentrates purchased increases by 60 kg per cow, but a larger proportion consists of ground ear silage, which has a low N content and is cheap compared with other concentrates. N accumulation and denitrification are reduced from 205 to 120 kg. At the low N mineralization rate, 73 kg more fertilizer N is required to achieve a similar N output. However, at both the high and the low mineralization rate, N accumulation occurs, implying that equilibrium has not been reached in either situation. The situation with the high mineralization rate is closer to equilibrium than that with the low one. The costs of some inputs, especially fertilizer and concentrates, decrease and others increase somewhat, resulting in an overall cost reduction of Dfl 90. The revenues for milk and meat increase by Dfl 195. Hence, income increases by Dfl 285.

The conclusion is that N mineralization rate under grassland does not influence the dairy farming system aiming at maximum labour income very much. However, some characteristics are strongly affected, such as N fertilizer input and N surplus. This result confirms the conclusion of Chapter 7 that a general restriction on N surplus is a delicate matter.
Optimization results for the other goals show similar effects (Table 9 in Appendix D). Under minimum volatilization losses the area under maize is expanded and some fodder beets are cultivated at the expense of grassland for conservation. This results in on-farm concentrate production. Under minimum N surplus the opposite occurs: the area under grassland used for conservation is expanded at the expense of cultivation of maize and fodder beet. For all three goals minimizing N losses, a large proportion of the roughage produced is sold. It should be used as far as necessary to achieve the minimum of 12 t milk per ha. This practice will lead to the lowest N losses.

7.6.2. Conditions required for fodder beet cultivation

At 'De Marke' fodder beets are cultivated on 6 ha of land, because they were expected to contribute substantially to achieving the goals. Fodder beets have a high energy and DVE yield per ha, a high energy content per kg and a negative OEB, are palatable, can be used to substitute purchased concentrates and are not very sensitive to drought periods. The disadvantages of fodder beets are that they require extra mechanization, are only available in the winter period and have a very low N content and a high sugar content (Biewinga et al., 1992). Fodder beets were selected as part of the dairy farming system in only very few optimizations .
Table 2 in Appendix D shows that fodder beets were selected when minimizing N surplus. When maximizing income no fodder beets are selected. At an increasing proportion of concentrates grown on-farm (Table 4, Appendix D), artificially dried grass is preferred over fodder beets and ground ear silage. This indicates that the costs associated with cultivation of fodder beets and ground ear silage are prohibitive. Total costs per kg feed, i.e. costs associated with cultivation of the crop and with feeding the product to the cattle as used in the model, are given in Table 7.12.
This table shows that growing and feeding fodder beets and ground ear silage is more expensive than purchasing concentrates, depending on the type. The costs associated with production of artificially dried grass are similar to those for the cheaper concentrate types. Hence, when limiting concentrate purchases, first artificially dried grass is produced, next, ground ear silage and finally, fodder

beets. Fodder beets will hardly ever be cultivated if labour income is to be maximized. Purchasing ground ear silage is cheaper than on-farm production.

Table 7.12 shows that, when maximizing labour income, the costs associated with fodder beet cultivation have to be substantially reduced for fodder beets to be selected. Reducing these costs alone will not be sufficient, as fodder beets are always cultivated in rotation with maize. To meet the requirement for an overall nitrate loss below 34 kg N ha^{-1}, a catch crop has to be cultivated after maize, increasing the costs. Maize can be harvested for silage or ground ear silage. Compared to purchased concentrates ground ear silage is expensive and compared to grass silage maize silage is expensive (Table 7.12).

The costs associated with fodder beet and maize production have been varied to assess at which level fodder beets are selected when maximizing labour income. The minimum amount of concentrates produced on-farm has been set to 25 %, so the results in the first column of Table 4 in Appendix D serve as a reference.

The cost of maize cultivation has been reduced by Dfl 600 ha^{-1}, i.e. the McSharry subsidy on maize. The total costs consist of those associated with production and storage as well as with feeding, for fodder beets Dfl 3780 ha^{-1} and Dfl 271 t^{-1}, respectively. Fodder beet cultivation enters the optimal dairy farming system when the costs associated with production and storage are reduced to Dfl 1400 ha^{-1} or the costs of feeding to Dfl 65 t^{-1}. If both are reduced at the same time, the reduction in each individual item can be smaller. At these price levels, maximum labour income remains the same as in the reference run. The area used for the production of artificially dried grass is reduced from 10 to 7 % and fodder beets are cultivated on 2 % of the area. Further reduction in the cost of fodder beet cultivation and feeding results in further substitution of artificially dried grass by fodder beets. The costs of ground ear silage are not reduced to such an extent that maize is harvested as such instead.

Table 7.12 Total costs of feeds in Dfl per kg dry matter.

Feed	Costs
Fodder beets	0.561
Ground ear silage (irrigated, catch crop)	0.509
Artificially dried grass (450 - 100 kg N)	0.344 - 0.392
Purchased concentrates	0.355 - 0.525
Maize silage (irrigated, catch crop)	0.362
Grass silage, 4 t (irrigated, 450 - 100 kg N)	0.287 - 0.338

All maize is made into whole plant silage and fed in summer. In winter grass silage is fed. Day grazing with maize supplementation is practised on 28 % of the area, receiving 350 kg N ha^{-1}. The remaining grassland area is used for day and night grazing, receiving 250 kg N ha^{-1}. No zero grazing is practised, as was the case in the reference run. Concentrate use per cow is 140 kg lower. N surplus is reduced by 14 kg. Hence, although labour income, milk production and stocking rate are the same as in the reference run, the dairy farming system differs. When minimizing N surplus or ammonia volatilization fodder beets are also cultivated at the lower price levels. Under minimization of nitrate leaching fodder beets will not be selected, unless a minimum labour income is introduced and fodder beets are very cheap.

This analysis shows that, at the price levels used in the model, the production of fodder beets and ground ear silage on-farm is far too expensive to compete with grass. However, if labour income is not the major objective, in some situations fodder beets may be cultivated. Although not analysed in detail, the same conclusion seems to apply to ground ear silage.

7.7. Discussion

7.7.1. Evaluation of the IMGLP model

Section 7.3 shows that, in general, the simulated results agree reasonably well with results from 'De Marke'. The IMGLP model for dairy farming produces realistic results when initialized for a specific situation.

However, there are some discrepancies between the model results and reality. Some of these discrepancies can be reduced by more detailed initialization and elaboration of the models. For instance, according to GRASMOD and the IMGLP model dairy cows calve on 1st February, while at 'De Marke' calving is spread over the year, leading to discrepancies in feed ration in summer and winter (Subsection 7.3.3). By introducing into the models an option for spreading of calving over the year, the situation at 'De Marke' can be more closely approached.

The models apply to the average situation at 'De Marke'. However, the soil on the farm is extremely heterogeneous (Biewinga et al., 1992), resulting in a wide variability in measured data. This complicates the initialization of the models for the average situation. For instance, Section 7.2 shows in particular that the relationships between N application, N uptake and dry matter yield for maize and fodder beet are difficult to derive from the experimental data.

Some model relationships can hardly be tested, as they have not yet been monitored or knowledge is lacking. For instance, ammonia volatilization was not measured at 'De Marke', but calculated on the basis of a theoretical concept. Hence, no conclusions can be drawn on the accuracy of calculated ammonia volatilization. Denitrification and accumulation are hard to measure and constitute the balancing item on the N balance. Although the results obtained by the Dairy Farming Model and at 'De Marke' agree reasonably well, the theoretical concepts in both systems differ.

7.7.2. Evaluation of measures taken at 'De Marke'

The target value for N surplus at 'De Marke' has been set at 128 kg, based on N policy objectives for nitrate leaching and ammonia volatilization and estimated denitrification losses. As discussed in Subsections 7.3.2 and 7.5.1, a target for N surplus is debatable. Section 7.5 shows that the setting of the target value to 128 kg has a very large influence on the dairy farming system. The land use practised at 'De Marke', which was selected to limit the N surplus to 128 kg N ha^{-1}, limits labour income. Column B in Table 7.11 shows that at the target N surplus, a substantially higher labour income is possible than being attained in simulation of the current system (Table 7.3). The main differences are less fodder beets and ground ear silage and a higher milk production per cow.
In the optimum situation with no restriction on N surplus, no maize would be cultivated. Introducing a restriction of 128 kg N results in 48 % of the area under maize (Table 7.11). Up to 20 % of the area under maize has little influence on labour income, while the targets for nitrate leaching and ammonia volatilization are met. At 'De Marke' 30 % of the area is cultivated with maize, resulting in a reduced labour income, but a more favourable N input:output ratio (Subsection 7.5.4).
Without a restriction on N surplus, cows are grazing day and night. Introducing the restriction on N surplus of 128 kg, leads to day-grazing with maize supplementation, resulting in a slightly reduced labour income, but an improved N input:output ratio. At 'De Marke' day grazing with maize supplementation is also practiced.
With no restriction on N surplus, all concentrates are purchased, while with the restriction, about 15 % of the concentrates is produced on-farm (Table 7.11). At 'De Marke' the target is to produce 50 % of the concentrates on farm and in 1993/94 47 % was achieved. When up to 25 % of the concentrates are produced on-farm, this has only a small influence on labour income and up to 50 % it does not influence N surplus. Up to 75 %, the concentrate type produced on-farm is artificially dried grass only and above that value also ground ear silage is produced. From an economic point of view, the target of 50 % on-farm

concentrate production for 'De Marke' is rather high, as it reduces income considerably and does not reduce N surplus (Subsection 7.5.3).

At an annual milk production level per cow of 8 500 kg, all land is in grass, day-and-night grazing is practised in stead of day grazing and more concentrates are purchased than in the simulated dairy farming system (cf Table 7, Appendix D and Table 7.3). This leads to a higher milk production per ha and consequently a higher income.

At a milk quota of 12 t ha-1 (Table 8, Appendix D), also all land is in grass, day-and-night grazing is practised and a smaller amount of concentrates is used than in the simulated system (Table 7.3). Reduction of ammonia emission from stable and storage is smaller in the optimum system, leading to a higher labour income per tonne of milk.

7.7.3. Concluding remarks

Based on the exercise of applying the set of models developed in this study to the situation at 'De Marke' the following remarks can be made:

- the models developed in this study are suited for exploring the opportunities for the development of dairy farming at a specific location, provided they can be initialized for that situation, as with 'De Marke';
- by further adapting the models to the situation at 'De Marke', they can be used to explore the potential offered by new ideas and techniques and the circumstances in which they would be appropriate;
- the target N surplus of 128 kg for 'De Marke' has a major influence on the dairy farming system implemented, while its value is at least debatable. Moreover, both in reality and according to the model this value cannot be attained under the current farm lay-out and management. It is debatable whether N surplus should be a specific goal at this moment. More detailed research is needed to improve existing knowledge on environmental factors and the processes determining accumulation and denitrification;
- the cultivation of concentrates or concentrate replacing crops on-farm, including those with a high energy:N-ratio, is debatable. It is costly and reduces total milk production, while the targets for N losses can also be attained with all land in grass;
- artificially dried grass is an option for the production of concentrates on-farm at 'De Marke';
- a large area under crops with a high energy:N-ratio (e.g. maize) to improve N efficiency in cattle is not necessary to achieve the targets for N losses;
- monitoring over a longer period is required at 'De Marke' to explain the large annual variability in measured data;

- it has been assumed at 'De Marke' that it is possible to apply more P than required on grassland and to apply less P than required on maize when the two are grown in rotation, without any effects on crop yields. This results in low overall P application rates. However, the effect on soil P status is not yet clear;
- average N uptake by grass without fertilizer application is only 56 kg N, while for maize it is about 90 kg. Mineralization measurements indicate a large N pool under grassland. The reasons for the low N uptake by grass are unclear and require more detailed research.

8. General discussion

The IMGLP methodology and the models developed in this study will be evaluated with respect to their suitability for exploring the options in dairy farming on sandy soils in the Netherlands. The results are discussed in the light of the aims of the study as described in Chapter 1 and experiences in applying the method. First, the potentials and limitations of the method are discussed (Section 8.1). Subsequently, interpretation of model results is considered, both in general terms and more specifically with respect to assumptions regarding technical relationships, including the reliability of model results (Section 8.2). In Section 8.3 future research, based on the results and understanding gained in this study, is indicated.

8.1. Potentials and limitations of the methodology

Policy measures to reduce nutrient losses in dairy farming are based on the fact that society no longer accepts environmental pollution at the present high level. The norms are a political issue and often based on diffuse and incomplete information. The dairy farming sector itself has to work out measures to meet these norms, though some measures are obligatory, such as incorporation of slurry in the soil. Measures are often directed towards one aspect, for instance nitrate leaching or P surplus, and the effects of various norms are not considered in an integrated way. An important advantage of the IMGLP method is that possible developments, policy measures and research priorities are considered in a consistent framework and that they can be mutually adapted.

IMGLP is well suited to making the implications of policy goals and measures explicit. By applying IMGLP to policy and farmers' goals, the conflicts between the views of both parties become evident and the opportunity costs of the various goals can be determined. Moreover, unintended effects, in so far as they are incorporated in the model environment, are revealed.

The aim of this study was to explore the potential of dairy farming systems on sandy soils in the Netherlands from both an environmental and an economic point of view. In Chapter 6 it has been shown, that through a step-by-step process of tightening the limiting values for environmental and economic goals, the boundaries of the accepted area, i.e. the area where each combination of goal variables is acceptable to each of the parties, can be established. Depending on the preferences of the party, i.e. its emphasis on a specific goal, the characteristics of the dairy farming system, such as grassland utilization method, cropping pattern, concentrate use, stocking rate, etc., may vary and hence, will lead to different scenarios for dairy farming.

The effect of policy measures, such as a levy on N surplus, artificial fertilizer or concentrates, can be assessed by comparing optimization results with and without these measures

The Dairy Farming Model can be used to identify the conditions required for selection of a specific technique, as was done in Subsections 7.6.2. A production technique may be expected to contribute substantially to one or more goals, but may not be not selected by the model, e.g. the cultivation of fodder beets. An analysis with the model may lead to the conclusion that the model lacks some essential constraints or relationships and can be improved. If that is not the case, the analysis may lead to the identification of measures to meet the required conditions, or the reason for not selecting the technique is acceptable but was overlooked at the start.

The Dairy Farming Model may also be used to assess the potentials of new production techniques that are expected to contribute to a more complete realization of at least one of the goals. In this case, new techniques have to be quantified in terms of inputs and outputs and their contributions to the various goals. Some techniques can be incorporated in the TCG models, such as better utilization of N by grasses or maize. Other techniques have to be incorporated in the IMGLP model, such as those leading to reduced ammonia volatilization from stable and storage constructions. Some have to be incorporated in both, for instance better utilization of nitrogen by cattle. Such techniques do not have to be applied yet. The results of such an exercise can also be used to assess whether or not it is worthwhile investing in a major research and development effort.

The method requires quantification of all techniques in terms of inputs and outputs, as well as in their contribution to the goals defined. In this process, gaps in knowledge may be revealed. To be able to run the model, unknown parameters have to be estimated as accurately as possible. After undertaking the optimization procedure a sensitivity analysis has to be carried out by varying the value of the specific parameter around the estimated one and repeating optimizations (Section 7.6.1). The effects of inaccuracies in the parameter estimate can then be established. By doing this for the most important relationships and parameters, research priorities can be set.

The optimization procedure provides the outer boundaries of the technical possibilities and indicates opportunities for dairy farming scenarios within these boundaries. For various reasons, it does not predict future developments. Each farmer has his own preferences with respect to techniques and goals and may be satisfied at different points along the development pathway towards environmentally-sound and economically viable dairy farming systems.

Moreover, policy goals may change with time or new techniques, that were not anticipated, may be developed.
A limitation of the IMGLP method is that quantifying a consistent set of input-output coefficients and deciding on the techniques to be considered, is very time consuming. A lot of information has to be combined and, as mentioned above, it is not always available. This influences the reliability of the model results (Section 8.2). Information has to be collected from many different sources to a well-balanced level of detail and all bits and pieces should be systematically related to each other. The Dairy Farming Model is defined on a ha basis. This complies with some policy goals, but for others a conversion has to be made. For instance the policy goal on ammonia volatilization is defined as a 70 % emission reduction compared with the level in 1980. The problem is that the emission in 1980 is unknown, but various estimates have been made.
In the model, optimization always leads to the best absolute value of the goal considered. Slightly less favourable values will not be considered, while in reality they may be equally satisfactory to the party concerned. As a consequence, a production technique may not be selected under a wide range of conditions, while with a small change it may suddenly become interesting. Most optimization software has a ranging option, but this only provides a sensitivity analysis of one parameter at a time in the IMGLP model, which is often not sufficient. By varying the values of the most important characteristics of the selected dairy farming system, the margins around it can be determined, as in Section 7.5 for a number of characteristics of the system at 'De Marke', such as P surplus, proportion of on-farm produced concentrates, proportion of the area under maize, etc. This reduces the risk of a production technique not being selected, because it is just below the optimum. However, that risk cannot be avoided completely.
Another limitation of IMGLP is that only linear relations can be used. Non-linear relationships have to be approached by linear means. This may lead to some inaccuracies. The production techniques defined in the Dairy Farming Model are discrete points and not defined as continuous functions. For instance, N application is set at various levels and is not handled by a function that is optimized. If that were the case, many non-linear relationships would have to be introduced, resulting in a very complicated non-linear programming model.

8.2. Interpretation of model results

Models are always an abstraction of reality. Relationships not defined in the model are not considered. Therefore, the results of the model must always be related to the defined model environment. At the moment, the Dairy Farming

Model applies to dairy farming on well-drained sandy soils in the Netherlands and the main issues addressed are production, and N and P fluxes in the system. However, the model has a flexible structure, which allows for its extension with additional goals, production techniques and restrictions, as well as additional soil types, water supply levels and crops. This requires appropriate modification of the TGC and IMGLP models.

8.2.1. Economic evaluation

From an economic point of view, the model gives very optimistic results. The economic results cannot be compared directly with those of commercial farms.
The data used in this study are based on a well-managed and organized dairy farming system and timely execution of all the necessary operations. To achieve this, the labour requirements, in this study based on norms, and costs may be higher in reality.
Commercial farms have a fixed area on a short term and a milk quota. Moreover, some farm-specific characteristics and costs were not taken into account in this study. The cost of machinery were based on costs under mutual usage. Generally, on a commercial farm, a farmer decides whether to buy equipment or not. This may result in slack equipment if it cannot be fully utilized, increasing the operational costs per hour. The cost of buildings and milking equipment were based on a herd of 100 cows, resulting in relatively low costs per cow compared with smaller herds. Hence, labour income as defined in this study does not represent real farm labour income, but serves as a reference base for comparison of the economic performance of selected production systems.
The optimization results represent the end of a development path with regard to the goals and restrictions imposed, while farms are continuously adapting to a changing environment.
However, the economic optimization results under the various scenarios are mutually comparable, as a consistent data base and similar starting points were used. The shifts in dairy farming systems due to changing restrictions are indicative of development possibilities in dairy farming. The economic relationships and trends are more important than the absolute figures, which are only relevant to the defined model environment.

8.2.2. Regional versus farm level

The Dairy Farming Model was applied at regional level (Chapter 6) and at farm level (Chapter 7). The results at regional level can only be translated to farm level if all the farms in a region are identical. However, Figure 6.10 shows that land use in most scenarios is very diverse and some types of land use are allocated to a very small proportion of the total area. Table 6.6 shows that in three out of four scenarios a mix of N application levels on grassland is selected. It would be practically impossible to apply these results to all the farms in a region. Moreover, farmers have their own specific preferences with respect to goals and production techniques (Van der Ploeg, 1993), and the conclusion in Chapter 6 was that a range of dairy farming systems is possible, as long as some general rules are observed. A mix of various farm types in a region is more realistic. If the model is applied to a specific region, an inventory of farmers' preferences should be made and taken into account. It may well be that calculated milk quota, farm size and number do not match reality. In which case, first of all the model should be screened for unrealistic assumptions. However, if no more essential errors are found, the results obtained with the model can be used to support and guide policy-makers in deciding on measures and norms. Hence, to translate regional results of the Dairy Farming Model to individual farms in a region an extensive post-model analysis will be required.

The Dairy Farming Model can also be applied at farm level, provided it can be initialized for the specific situation. The results can be used to guide development of the dairy farming system, while taking into account the farmers' preferences with regard to specific goals and techniques. Farm size, as determined by land area and milk quota, can be fixed at the present value, but it can also be varied to explore its influence on farm performance.

So far, all environmental goals refer to the whole region. For nitrate leaching this is the most appropriate scale, as groundwater pumped for human consumption is a mixture of what is found in a catchment area. For ammonia volatilization, however, farm level is most appropriate, as ammonia is deposited at only a limited distance from the source (Lekkerkerk, 1995; Heij & Schneijder, 1995). For P the most appropriate scale is field scale. Even if P surplus at farm level is 0, considerable amounts of P can be lost from individual fields.

It would be desirable to establish some sort of interaction between developments at regional and farm level. One way would be to start with optimization at regional level. Based on the results, several farm types can be identified. Subsequently, optimizations could be carried out for each farm type at farm level. Next, these results could be aggregated to regional level again and compared to the results of the initial optimization at that level. This may lead to modifications in the initial set of constraints. The set of goals optimized at both levels may differ. The procedure can be repeated until optimizations at both levels matching one another. This procedure is being tested by a group of scientists at the moment, but it appears to be complicated (Kruseman et al., 1995).

8.2.3. Reliability of the model results

Reliability of the model results depends on various aspects. First of all, the reliability of input parameters and relationships in the model definition are important.

For instance, in GRASMOD soil N fluxes are not in equilibrium (Chapters 2 and 3). The amount of N annually available from mineralization should be adapted to each specific grass production and utilization technique. However, the soil organic N pool is so large that the annual changes are relatively small and hardly affect the overall results. The results from GRASMOD can be considered valid for several years. If a long time horizon is considered, mineralization rate should be adapted to the grass production and utilization technique. One option is to define transfer coefficients similar to those defined in the TCG models for maize and fodder beets.

In the IMGLP model the summer ration was not optimized, but determined by the grass production and utilization technique. Grass is the basic component of the ration, supplemented with maize and/or concentrates. This ration may not lead to the lowest possible N losses. Combinations of other crops, such as a grain crop, alfalfa or red clover were not considered. However, two types of concentrates are available in summer, a standard one and a low-N one. These are fed in such a combination that the DVE surplus is kept as low as possible. Calves have a fixed ration according to the feeding standards for the first three months of their lives. This leads to an unnecessarily high N intake and N excretion. However, this relates to only part of the year and a small part of the dairy farming system.

These types of limitations can all be alleviated by refinement and modification of the model.

Another aspect related to the reliability of model results is the reliability of input data. Many parameters were used on a wide range of processes and from many sources. The best possible estimates were made, based on information from the literature, experiments and experts. Knowledge is lacking or insufficient with regard to some aspects in the Dairy Farming Model. It is important to be continuously alert to new information becoming available from various sources. To evaluate model results fully with respect to all parameters is very complex and constitutes a study in itself.

8.3. Priorities for further research

The model results and their interpretations may raise new issues, both regarding process oriented experimental research and on further refinement and extension of the Dairy Farming Model.

Further refinement would be required with respect to the following aspects. The feeding standard has been applied in the model, but at 'De Marke' dairy cows are fed 10 to 15 % more energy than is required according to the standard to attain the milk production target. The feeding standards are based on experiments with dairy cows producing 6 000 kg milk per lactation. Extrapolation of these results seems debatable. Feeding regime has a major influence on the model results and hence, this aspect requires attention.

Changes in soil fertility are difficult to assess. For both N and P, storage in the soil is so large that calculated changes are hard to verify. The effect of a P application equal to the amount transported from the field on soil fertility on the long term is not clear. It is uncertain how P status of the soil and, the associated crop yields will develop over a longer period. Hence, the development of soil fertility as influenced by characteristics of the production system on the long term requires attention.

Chapters 4 and 7 indicate that N fluxes in the soil, with respect to accumulation, denitrification and N uptake without fertilizer application, as influenced by characteristics of the production system are difficult to quantify. The relationship between N losses and the composition of the ration of cattle deserves more attention. The definition of landscape goals needs to be improved. The results of process-oriented research can be used to improve the model. This is part of normal practice in the maintenance of models.

The Dairy Farming Model applies to the average situation on well-drained sandy soils in the Netherlands and to an average year. Interesting possibilities for extension are discussed below.

The addition of other soil types, such as clay and peat soils, and of different levels of water availability is required to adapt the model for application to a distinct region or farm, such as 'De Marke'. Assessment of the influence of risk and annual variability in crop yields, mineralization rate, weather, etc. on the results may improve the scope for application of the model in practice.

The addition of other goals, such as energy use and nature development would improve the scope for development of integrated dairy farming, as these goals form an integral part of such systems. Artificially dried grass is an option in some scenarios, but it requires a lot of energy. Low-emission slurry application requires more energy than surface application. However, less artificial fertilizer is necessary, leading to a lower indirect energy input. By quantifying energy inputs and flows similar to N and P flows the trade-offs between minimization of nutrient losses and use of energy could be established. Landscape and/or nature development is an option in some regions. For instance, the development of species-rich haylands may improve the attractiveness of a region. Some areas may require buffer zones to prevent species from disappearing completely.

The Dairy Farming Model could be used for determining the prospects for new technologies. They have to be defined in terms of inputs and outputs and their contribution to the various goals. A distinction between process and product innovation could be made. A process innovation may apply to all crops, such as fertilizer application adapted to the heterogeneity of the field. A product innovation is crop-specific, such as production of grass protein for other purposes than animal feed. This will affect the point at which the technology acts upon the dairy farming system and, hence, the modelling method.

The addition of other crops and integration with arable farming may reveal the prospects for mixed farming, either at farm or regional level. Slurry can be used on arable farms and crop residues can be used on dairy farms. Concentrates can be produced on arable farms and fed in dairy farming. This may lead to an improved regional mineral balance when compared to dairy farming only, and for arable farming, grass and other crops offer at least a partial solution to soil-borne diseases in the rotation.

Making the model dynamic in time, will enable the development pathways to be explored from the present situation to the intended one. This requires the introduction of rates of change from current practices to new ones.

A farming style can be defined in terms of preferences with respect to measures, production techniques and goals. This addition may lead to better identification and exploration of the various corners of the accepted area. Model results will be better directed towards the analysis of possible developments in a specific region.

References

Aarts, H.F.M., 1994a. Italiaans raaigras als vanggewas na maïs (Italian rye grass as a catch crop after maize). In: Tussenbalans 1992-1994. Rapport nr. 10, De Marke, Hengelo (Gld), 45-51.

Aarts, H.F.M., 1994b. De kwaliteit van het grondwater van De Marke (The quality of the groundwater at De Marke). In: Tussenbalans 1992-1994. Rapport nr. 10, De Marke, Hengelo, 127-130.

Aarts, H.F.M., 1994c. Stikstofleverend vermogen van de bodem (Nitrogen supply by the soil). In: Tussenbalans 1992-1994. Rapport nr. 10, De Marke, Hengelo, 118-122.

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

Aarts, H.F.M. & H. van Keulen, 1990. De praktische gevolgen van verscherpte milieu-eisen voor de weide- en voederbouw op zandgrond: een theoretische benadering (The consequences of tightening environmental requirements for cultivation of grass and fodder crops on sandy soils: a theoretical approach). Verslag 139, CABO, Wageningen, 31 p.

Aarts, H.F.M. & N. Middelkoop, 1990. De invloed van bodemeigenschappen en bemesting, op de opbrengst van maïs en de emissies van ammoniak en nitraat (The influence of soil characteristics and fertilization on the yield of maize and the emission of ammonia and nitrate). Verslag 131, CABO, Wageningen, 55p.

Aarts, H.F.M. & N. Middelkoop, 1994. Mineralenbalansen en -kringlopen (Mineral balances and cycles). In: Tussenbalans 1992-1994. Rapport nr. 10, De Marke, Hengelo (Gld), 61-85.

Agricultural Economics Research Institute & Netherlands Central Bureau for Statistics (LEI & CBS), 1975-1995. Landbouwcijfers (Agricultural Statistics), Den Haag.

Alberda, Th., 1968. Dry matter production and light interception of crop surfaces. IV. Maximum herbage production as compared with predicted values. Netherlands Journal of Agricultural Science 16, 142-153.

Alberda, Th., 1973. Potential protein production of temperate grasses. In: J.G.W. Jones. The biological efficiency of protein production. Cambridge University Press, Cambridge, 119-130.

Alberda, Th. & L. Sibma, 1968. Dry matter production and light interception of crop surfaces. 3. Actual herbage production in different years as compared with potential values. Journal of the British Grassland Society 23(3), 206-215.

Asijee, K. (Ed.), 1993. Handboek voor de Rundveehouderij (Manual for cattle husbandry). IKC-RSP, Ministerie LNV, Lelystad, 607 p.

Baan Hofman, T. & L. en Holte, 1992. Veldproeven met gras, maïs en voederbieten. Onderzoek in 1990 op 'De Marke' (Field experiments on grass, maize and fodder beet. Research in 1990 at 'De Marke'). Rapport nr. 8, De Marke, Hengelo (Gld), 31 p.

Baan Hofman, T. & L. ten Holte, 1995. Veldproeven met gras, klaver, maïs en voederbieten. Onderzoek in 1991 op 'De Marke' (Field experiments on grass, clover, maize and fodder beet. Research in 1991 at 'De Marke'). Rapport nr. 11, De Marke, Hengelo (Gld), 31 p.

Beek, C.G.E.M. van, 1987. Chemische processen in het grondwater tijdens de stroming naar het puttenveld (Chemical processes in ground-water during its flow to the pumping fields). In: C.G.E.M. van Beek (Ed.), Landbouw en drinkwatervoorziening, oriënterend onderzoek naar de beïnvloeding van de grondwaterkwaliteit door bemesting en het gebruik van bestrijdingsmiddelen. Onderzoek 1982-1987. KIWA mededeling 99, KIWA, Nieuwegein, 6.1-6.16.

Beek, M.A. van der & P. Wilting, 1991. Rüben: Weniger Stickstoff durch Reihendügung? Top Agrar. 3, 110-111.

Berendse, F., C. Laurijsen & P. Okkerman, 1988. The acidifying effect of ammonia volatilized from farm-manure on forest soils. Ecological Bulletins 39, 136-138.

Berentsen, P.B.M & G.W.J. Giesen, 1995. An environmental-economic model at farm level to analyse institutional and technical change in dairy farming. Agricultural Systems 49, 153-175.

Biewinga, E.E., H.F.M. Aarts & R.A. Donker, 1992. Melkveehouderij bij stringente milieunormen - Bedrijfs- en onderzoeksplan van het Proefbedrijf voor Melkveehouderij en Milieu (Dairy farming under environmental restrictions - Farm and research plan for the experimental farm for Dairy Farming and Environment). Rapport nr. 1, De Marke, Hengelo (Gld), 284 p.

Boer, Th. de, 1966. Nitrogen effect on the herbage production of grasslands on different sites. Proceedings of the Xth International Grassland Congress, 199-204.

Boer, W.J. de, A. Keen & G.J. Monteny, 1994. Het effect van spoelen op de ammoniakemissie uit melkveestallen (The effect of flushing on the ammonia emission from dairy cattle houses). IMAG-DLO rapport 94-6, Instituut voor Milieu- en Agritechniek, Wageningen, 33p.

Boons-Prins, E.R. & G.W.J. van de Ven, 1993. Uitbreiding van het graslandbeheersmodel GRASMOD: invloed van de opfok van jongvee voor de melkveehouderij op stikstofstromen in grasland (Extension of the grassland management model GRASMOD: influence of raising young stock for dairy farming on nitrogen flows in grassland). Verslag 171, CABO-DLO, Wageningen, 38 p.

Boumans, L.J.M., C.R. Meinardi & G.J.W. Krajenbrink, 1989. Nitraatgehalten en kwaliteit van het grondwater onder grasland in de zandgebieden (Nitrate concentrations and quallity of groundwater under grassland on sandy soils). Rapport no 728472013, RIVM, Bilthoven, 43p.

Boumans, L. & D. Fraters, 1995. De kwaliteit van het bovenste grondwater (The quality of the upper ground-water). In: Aarts, H.F.M. (Ed.), Weide- en voederbouw op De Marke: op zoek naar de balans tussen produktie en emissie. Rapport nr. 12, De Marke, Hengelo (Gld), 45-62.

Breeuwsma, A. & M.E.G. Berghs (Eds.), 1993. Fosfaatevenwichtsbemesting. Analyse van de fosfaatproblematiek en de kennisbehoefte voor de invulling van de eindnorm (Phosphate application aiming at an equilibrium in the soil. An analyses of the fosfate problems and knowledge requirements to set a final standard). Onderzoek inzake de mest- en ammoniakproblematiek in de veehouderij 17, 48 p.

Bristow, A.W.,J.C. Ryden & D.C. Whitehead, 1987. The fate at several time intervals of 15-N-labelled ammonium nitrate applied to an established grass sward. Journal of Soil Science 36, 245-254.

Bussink, D.W., 1992. Ammonia volatilization from grassland receiving nitrogen fertilizer and rotationally grazed by cattle. Fertilizer Research 33, 257-265.

Bussink, D.W., 1994. Relationships between ammonia volatilization and nitrogen fertilizer application rate, intake and excretion of herbage nitrogen by cattle on grazed swards. Fertilizer Research 38, 111-121.

Central Bureau for Animal Feeds (CVB), 1993. Voedernormen Landbouwhuisdieren en Voederwaarde veevoeders, verkorte tabel (Feeding standard for domestic animals and nutritional value of feed stuffs). Produktschap voor Veevoeder, cvb-reeks nr. 5, Lelystad, 48 p.

Coppoolse, J., A.M. van Vuuren, J. Huisman, W.M.M.A. Janssen, A.W. Jongbloed, N.P. Lenis & P.C.M. Simons, 1990. De uitscheiding van stikstof, fosfor en kalium door landbouwhuisdieren, nu en morgen (Extcretion of nitrogen, phosphorus and potassium by domestic animals, now and tomorrow). Onderzoek inzake de mest- en ammoniakproblematiek in de veehouderij 5, FOMA, DLO, Wageningen, 132 p.

Corporaal, J. & A. Steg, 1990. Bemonstering, kwaliteit en voederwaarde van graskuil (Sampling, quality and nutritional value of grass silage). Rapport 123, PR & IVVO, Lelystad, 36 p.

Corré W.J. & C.A.M. de Klein, 1990. Stikstofverlies en milieubelasting door denitrificatie in de bovengrond van grasland (Nitrogen loss and environmental pollution by denitrification in the top soil of grassland). In: A. Breeuwsma & H.A.C. Verkerk. Milieu-effecten van nitraat en fosfaat uit dierlijke mest: problemen en oplossingen. Onderzoek inzake de mest- en ammoniakproblematiek in de veehouderij 7, Dienst Landbouwkundig Onderzoek, Wageningen, 27-34.

Cowling, D.W., 1966. The response of grass swards to nitrogenous fertilizer. Proceedings of the Xth Grassland Congress, 204-209.

Debruck, J. von, 1979. Rübenblatt - so wertvoll wie eine Stallmistgabe. Pflanzliche Production, DLG-Mitteilungen 18, 1030-1032.

Dijk, J.P.M. & A.L.J. van Vliet, 1990. Bedrijfsuitkomsten in de landbouw (BUL): boekjaren 1985/86 t/m 1988/89 (Farm results: years 1985/86-1988/89). Periodieke Rapportage 11-88/89, LEI-DLO, Den Haag.

Dijk, T.A. van, 1985. De uitspoeling van mineralen op bouwland waaraan jaarlijks drijfmest wordt toegediend (Leaching of minerals from arable land, receiving slurry annually). Rapport 2-85, IB, Haren.

Dijk, W. van (Ed.), 1993. Teelt van maïs (Maize cultivation). Teelthandleiding 58, S-35, IKC-Veehouderij, PAGV, Lelystad, 126 p.

Duijvenbooden, W. van (Ed.), 1989. De kwaliteit van het grondwater in Nederland (The quality of ground-water in the Netherlands). Rapport 728820001, RIVM, Bilthoven, 307 p.

Egmond, F. van, 1974. The ionic balance of the sugar-beet plant. Proefschrift Landbouwhogeschool, Wageningen,70 p.

Erp, P.J. van, A.P. Withmore & P. Wilting, 1993. Mineralisatie van stikstof uit gewasresten van suikerbieten na de oogst (Mineralization of nitrogen from sugar beet residues after harvest). Meststoffen 1993, 64-69.

Es, A.J.H. van, 1978. Feed evaluation for ruminants. I. The systems in use from may 1977 onwards in the Netherlands. Livestock Production Science 5, 331-345.

Foundation Green Label, 1993. Emissie-arme stallen, beoordelingsrichtlijn (Low-emission stables, directives for criteria). Foundation Green Label, 32p.

Garwood, E.A. & J.C. Ryden, 1986. Nitrate loss through leaching and surface runoff from grassland: effects of water supply, soil type and management. In: Meer, H.G. van der, R.C. Ryden & G.C. Ennik (Eds.). Nitrogen fluxes in intensive grassland systems. Martinus Nijhoff Publishers, Dordrecht, 99-113.

Geelen, P.M.T.M., 1992. Invloed van het tijdstip van stikstofbemesting op de opbrengst en kwaliteit van suikerbieten (Influence of timing of nitrogen applications on the yield and quality of sugar beet). Jaarboek 1991/1992, verslagen van in 1991/1992 afgesloten onderzoeksprojecten op Regionale Onderzoekscentra en het PAGV, Publikatie nr. 64, PAGV, Lelystad, 63-67.

Goossensen, F.R. & P.C. Meeuwissen (red.), 1990. Advies van de Commissie Stikstof (Recommendations by the Committee Nitrogen). Onderzoek inzake de mest- en ammoniakproblematiek in de veehouderij 9, Ministerie LNV, VROM en V&W, Ede, 93 p.

Groenwold, J. & J.A. Keuning, 1988. De relatie tussen de samenstelling van koeie-urine en het optreden van urinebrandplekken in grasland (The relation between the composition of cow urine and the incidence of scorching in grassland). Verslag 94, CABO, Wageningen, 33 p.

Hack-ten Broeke, M.J.D. & W.J.M. de Groot, 1995. De uitspoeling van nitraat naar het grondwater (Leaching of nitrate to the ground-water). In: Aarts, H.F.M. (Ed.), Weide- en voederbouw op De Marke: op zoek naar de balans tussen produktie en emissie. Rapport nr. 12, De Marke, Hengelo (Gld), 33-44.

Hassink, J., D.W. Bussink, O.Oenema, J.G. Kroes, M.J.D. Hack-ten Broeke & H.G. van der Meer, 1994. Verliezen en vastlegging van stikstof bij grasland en maïs (Losses and immobilisation of nitrogen in grassland and maize). In: Haan, M.H.A. de & N.W.M. Ogink. Naar veehouderij en milieu in balans, 10 jaar FOMA onderzoek; Rundvee. DLO, Wageningen, 73-92.

Hauck, R.D. & K.K. Tanji, 1982. Nitrogen transfers and mass balances. In: Stevenson, F.J. (Ed.). Nitrogen in agricultural soils. Agronomy Monograph no. 22, Madison, Wisconsin, USA, 891-925.

Heij, G.J. & T. Schneider (Eds.), 1995. Eindrapport Additioneel Programma Verzuringsonderzoek, derde fase (1991-1994) (Final Report Dutch Priority Programme On Acidification, third phase (1991-1994)). Rapport nr. 300-05, Dutch Priority Programme on Acidification, RIVM, Bilthoven, The Netherlands.

Hennen, H.G.J, 1995. DETECTOR, knowledge-based systems for dairy farm management support and policy analysis. Methods and applications. Onderzoeksverslag 125, LEI-DLO, Den Haag, 205 p.

Hijink, J.W.F. & A.B. Meijer, 1987. Het koemodel (The cow model). Publikatie nr. 50, PR, Lelystad, 52 p.

Hilhorst, G.J., 1995. Ervaringen met weide- en voederbouw (Experiences with grass and fodder cultivation). In: Aarts, H.F.M. (Ed.). Weide-en voederbouw op De Marke: op zoek naar de balans tussen produktie en emissie. Rapport nr. 12, De Marke, Hengelo (G ld), 3-14.

Holliday, R. & D. Wilman, 1965. The effect of fertilizer nitrogen and frequency of defoliation on yield of grassland herbage. Journal of the British Grassland Society 20, 32-40.

Holte, L. ten & H. van Keulen, 1989. Effects of white and red clover as a green manure corp on growth, yield and nitrogen response of sugar beet and potatoes. In: P.Placquaert and R. Haggar (Eds.), Legumes in farming systems, 16-24.

Houba, V.J.G., 1973. Effect of nitrogen dressings on growth and development of sugar-beet. Proefschrift, Landbouwuniversiteit, Wageningen, 65 p.

Janssen, B.H. & H.W. Verveda, 1988. Organische stof en bodemvruchtbaarheid (Organic matter and soil fertility). Vakgroep Bodemkunde en Plantenvoeding, Landbouwuniversiteit Wageningen, 215 p.

Jarvis, S.C., D. Barraclough, J. Williams & A.J. Rook, 1991. Patterns of denitrification loss from grazed grassland: effects of N fertilizer inputs at different sites. Plant and Soil 131, 77-88.

Jarvis, S.C., D.J. Hatch & D.R. Lockeyer, 1989. Ammonia fluxes from grazed grassland: annual losses from cattle production systems and their relation to nitrogen inputs. Journal of Agricultural Science Cambridge 113, 99-108.

Jarvis, S.C., M. Sherwood & J.H.A.M. Steenvoorden, 1987. Nitrogen losses from animal manures: from grazed pastures and from applied slurry. In: H.G. van der Meer, R.J. Unwin, T.A. van Dijk & G.C. Ennik. Animal manure on grassland and fodder crops. Fertilizer or waste? Developments in Plant and Soil Sciences no 30, Martinus Nijhoff Publishers, Dordrecht, 195-212.

Jong, P. 't, C. Hermans & H.F.M. Aarts, 1989. Het mineralenoverschot van de Gelderse landbouw en het effect van beleidsmaatregelen (The mineral surplus of Gelrian agriculture and the effect of policy measures). Verslag 114, CABO, Wageningen, 171 p.

Kamp, A. van der, P.P.H. Kant & A.J.H. van Lent, 1993. Bedrijfseconomische en milieutechnische gevolgen van emissie-arme bedrijfssystemen op melkveebedrijven (Farm economic and environmental consequences of low-emission farm systems on dairy farms). PR-rapport 149, Proefstation voor de Rundveehouderij, Schapenhouderij en Paardenhouderij, Lelystad, 165p.

Keulen, H. van & N.G. Seligman, 1987. Simulation of water use, nitrogen nutrition and growth of a spring wheat crop. Pudoc, Wageningen, 310 p.

Keulen, H. van & G.W.J. van de Ven, 1988. Application of Interactive Multiple Goal Linear Programming-Techniques for analysis ans planning of regional agricultural development: a case study for the Mariut region (Egypt). In: Boussard, J. M. (Ed.). Socio-economic factors in land evaluation. Proceedings of a conference held in Brussels, 7-9 Oct. 1987, Commission of European Communities, Luxembourg, 36-56.

Korevaar, H. & D.J. den Boer, 1990. Practical measures to reduce nutrient losses from grassland systems. Proceedings no 310, Fertiliser Society, London, 34 p.

Kruseman, G., R. Ruben, H. Hengsdijk & M.K. van Ittersum, 1995. Farm household modelling for estimating the effectiveness of price instruments in land use policy. Neth. Journal of Agric. Science 43, 111-123.

K.U. Leuven, S.E.S, B.D.B, B.I.V.B., 1985. Proefveld te Helecine. Meetgegevens - groeiseizoen 1982-1985 (Field experiment in Helecine. Measurements 1982-1985)..

Lammers, H.W., 1983. Gevolgen van het gebruik van organische mest op bouwland (The consequences of using manure on arable land). Consulentschap voor Bodemaangelegenheden in de Landbouw, 44 p.

Lammers, H.W., 1984. Een berekende stikstofwerkingscoefficient voor diverse dierlijke organische mestsoorten (A calculated nitrogen efficacy for several types of animal manure). De Buffer 30, 169-197.

Langeweg, F., 1989. Zorgen voor morgen, nationale milieuverkenning 1985-2010 (Taking care of tomorrow, a national exploration of the environment). RIVM, Samson H.D. Tjeenk Willink, Alphen aan de Rijn, 456 p.

Lantinga, E.A., 1985. Productivity of grasslands under continuous and rotational grazing. Proefschrift, Landbouwuniversiteit, Wageningen, 111 p.

Lekkerkerk, L.J.A., G.J. Heij & M.J.M Hootsmans (Eds.), 1995. Ammoniak: de feiten (Ammonia: the facts). Rapport nr. 300-06, Dutch Priority Programme on Acidification, RIVM, Bilthoven, The Netherlands, 95 p.

MacDiarmid, B.N. & B.R. Watkin, 1972. The cattle dung patch. 3. Distribution and rate of decay of dung patches and their influence on grazing behaviour. Journal of the British Grassland Society 27, 48-54.

MacLusky, D.S., 1960. Some estimates of the areas of pasture fouled by the excreta of dairy cows. Journal of the British Grassland Society 15, 181-188.

Maddux, L.D., C.W. Raczkowski, D.E. Kissel & P.L. Barnes, 1991. Broadcast and subsurface-banded urea nitrogen in urea ammonium nitrate applied on corn. Soil Science Society of America Journal 55, 264-267.

Maidl, F.X., 1990. Stickstofverwertung bei Mais. Maïs-DMK 3/90, 22-24.

Mandersloot, F., 1989. Simulatie van voeding en groei van jongvee (Simulation of feeding and growth of young stock). Rapport 116, PR, Lelystad, 61 p.

Mandersloot, F., 1992. Bedrijfseconomische gevolgen beperking stikstofverliezen op melkveebedrijven (Farm economic consequences of reducing nitrogen losses at dairy farms). Rapport 138, PR, Lelystad, 248p.

Meer, H.G. van der, 1982. Efficient use of nitrogen on grassland farms. In: Corrall, A.J. (Ed.) Efficient Grassland Farming. Occasional Symposium of the British Grassland Society, No. 14, Reading, United Kingdom, 61-68.

Meer, H.G. van der & P.C. Meeuwissen, 1989. Emissie van stikstof uit landbouwgronden in relatie tot bemesting en bedrijfsvoering (Emission of nitrogen from soils in agricultural use in relation to fertiltizer application and farm management). Landschap 1, p 19-32.

Meer, H.G. van der & M.G. van Uum-van Lohyuzen, 1986. The relationship between inputs and outputs of nitrogen in intensive grassland systems. In: H.G. van der Meer, J.C. Ryden & G.C. Ennik (Eds.), Nitrogen fluxes in intensive grassland systems, Martinus Nijhoff Publishers, Dordrecht, 1-18.

Meer, H.G. & M.G. van Uum-van Lohuyzen, 1989. Benutting en verliezen van stikstof uit de mest en urine van weidend vee (Utilization and losses of N from faeces and urine from grazing cattle). Gebundelde Verslagen 30, Nederlandse Vereniging voor Weide- en Voederbouw. 65-79.

Meer, H.G. van der & W.F. Wedin, 1989. Present and future role of grasslands and fodder crops in temperate countries with special reference to over-production and environment. Proceedings XVI International Grassland Congress, Nice, France.

Meer, H,G, van der & D.C. Whitehead, 1990. The fate of nitrogen in animal excreta applied to grassland. Paper presented at the 13th General Meeting of the European Grassland Federation, Bansk Bystrica, Czechoslovakia, 25-29 June 1990, CABO-report 141, 10 p.

Meester, G., 1980. Doeleinden, instumenten en effecten van het landbouwbeleid in de EG (Goals, instruments and effects of the common agricultural policy in the EC). Verslag no 1.15, LEI, Den Haag, 237 p.

Meijer, A., N. Middelkoop & C. de Vries, 1994. Veehouderij (Animal husbandry). In: Tussenbalans 1992-1994. Rapport nr. 10, De Marke, Hengelo (Gld), 4-37.

Middelkoop, N., 1989. Effecten van mest en urine op de produktiviteit van grasland (Effects of faeces and urine on the productivity of grassland). Doctoraal scriptie, Vakgroep Landbouwplantenteelt en Graslandkunde, Landbouwuniversiteit Wageningen, 63 p.

Middelkoop, N., 1994. Ammoniakemissie (Ammonia emission). In: Tussenbalans 1992-1994. Rapport nr. 10, De Marke, Hengelo (Gld), 107-117.

Middelkoop, N. & H.F.M. Aarts, 1991. De invloed van bodemeigenschappen, bemesting en gebruik op de opbrengst en de stikstofemissies van grasland op zandgrond (The influence of soil characteristics, fertilization and use on the yield and nitrogen emission of grassland on sandy soils). Verslag 144, CABO-DLO, Wageningen, 78 p.

Min. of Agriculture, Nature Management and Fisheries (LNV), 1989. Natuurbeleidsplan (Nature Policy Plan). SDU Uitgeverij, Den Haag, 179 p.

Min. of Agriculture, Nature Management and Fisheries (LNV), 1993. Notitie Mest en Ammoniakbeleid 3e fase (Note on the manure and ammonia policy 3rd phase). Tweede Kamer, 1992-1993, 19 882, nr. 34, SDU, Den Haag, 55 p.

Min. of Housing, Spatial Planning and Environment (VROM), 1989. Nationaal Milieubeleidsplan: kiezen of verliezen (National environmental policy plan: chosing or losing). Tweede Kamer, vergaderjaar 1988-1989, 21 250, nrs. 1-2, SDU Uitgeverij, Den Haag, 297 p.

Min. of Housing, Spatial Planning and Environment (VROM), 1994. Nationaal Milieubeleidsplan 2: milieu als maatstaf (National environmental policy plan 2: environment as a criterion). Tweede Kamer, vergaderjaar 1993-1994, 23 560, nrs. 1-2, SDU Uitgeverij, Den Haag, 248 p.

Min. of Transport, Public Works and Water Management (V&W), 1989. Derde Nota Waterhuishouding, Water voor nu en later (Third Note on Water Economy, Water for now and later). Tweede Kamer, vergaderjaar 1988-1989, 21137 nrs 1-2, SDU Uitgeverij, Den Haag, 258 p.

Mulder, E.M. & J.F.M. Huijsmans, 1994. Beperking van ammoniakemissie bij mesttoediening. Overzicht metingen DLO-veldmeetploeg 1990-1993 (Reduction of ammonia volatilization at slurry application. Overview of measurements DLO-field measurement team). Onderzoek inzake de mest- en ammoniakproblematiek in de veehouderij 18, Wageningen, 71 p.

National Reference Centre for Agriculture (IKC), 1991. Het nieuwe eiwitwaarderingssysteem voor melkvee (A new protein valuation system for dairy cattle). Publikatie nr. 8, IKC-Veehouderij, Ministerie LNV, Lelystad, 52 p.

National Reference Centre for Agriculture (IKC), 1992. Kwantitatieve informatie 1992-1993 voor de Akkerbouw en de Groenteteelt in de volle grond (Kwantitative Information for arable farming). Ministerie LNV,IKC-AGV, Lelystad, 212 p.

National Reference Centre for Agriculture (IKC), 1993. Kwantitatieve Informatie Veehouderj 1993-1994 (Quantitative Information for animal husbandry 1993-1994). Ministerie LNV, IKC-Veehouderij, Ede, 263 p.

Neeteson, J.J. & P.A.I. Ehlert, 1989. Environmental aspects of applying inorganic fertilizers to sugar beet. Proceedings 52nd Winter Congress, Intern. Inst. for Sugar Beet Research, Brussels, 79-91.

Neeteson, J.J., J. Hassink & O.Oenema, 1991. Mineralisatie en immobilisatie van stikstof in de bodem (Mineralization and immobilization of nitrogen in the soil). In: Meer, H.G. van der (Ed.). Stikstofbenutting en -verliezen van gras- en maïsland, Onderzoek inzake de mest- en ammoniakproblematiek in de veehouderij 10, 62-80.

Netherlands Scientific Council for Government Policy (WRR), 1984. Bouwstenen voor een geïntegreerde landbouw (Building bricks for integrated agriculture). Preliminary and backgroundstudies no. V44, SDU Uitgeverij, Den Haag, 196 p.

Nijkamp, P & J. Spronk, 1980. Interactive Multiple Goal Programming: an evaluation and some results. In: Fandel, G. & T. Gal (Eds.). Multiple Criteria Decision Making, Theory and Application, Proceedings third conference, Springer-verlag, Berlin, 278-293.

Pelser, L. (Red.), 1988. Handboek voor de Rundveehouderij (Manual for cattle husbandry). PR, Lelystad, 376 p.

Peterson, R.G., H.L. Lucas & W.W. Woodhouse Jr., 1956. The distribution of excreta by freely grazing cattle and its effect on pasture fertility: I. Excretal distribution. Agronomy Journal 48, 440-444.

Ploeg, J.D. van der, 1993. Bedrijfsstijlen en classificatieschema's: over de aard van agrarische ontwikkelingsprocessen (Farming styles and classification: on the nature of agricultural development processes). Tijdschrift voor Sociaal Wetenschappelijk onderzoek van de landbouw 8 (1), 50-70.

Poccock, T.O., G.F.J. Milford & M.J. Armstrong, 1990. Storage root quality in sugarbeet in relation to nitrogen uptake. Journal of Agricultural Science 115, 355-362.

Prins, W.H., 1983. Limits to nitrogen fertilizer on grassland. Proefschrift, Landbouwhogeschool, Wageningen, 122 p.

Prins, W.H., K. Dilz & J.J. Neeteson, 1988. Current recommendations for nitrogen fertilisation within the EEC in relation to nitrate leaching. Proceedings 276. The Fertiliser Society, London, 27 p.

Putten, A.H.J. van der & W.J. van Laarhoven, 1994. Theoretische berekeningen voor praktijkbedrijven: een validatie van FARM-MIN (Theoretical calculation for commercial farms: a validation of FARM-MIN). AB-DLO-notitie int. 8, AB-DLO, Wageningen, 54 p.

Putten, A.H.J. van der & H.G. van der Meer, 1995. Verkenning van streefwaarden voor het overschot op de stikstofbalans van melkveebedrijven (An exploration of target values for nitrogen surplus on dairy farms). Rapport 45, AB-DLO, Wageningen, 56 p.

Rabbinge, R., 1993. The ecological background of food production. In: Crop protection and sustainable agriculture. John Wiley & Sons, Chichester (Ciba Foundation Symposium 177), 2-29.

Reid, D., 1970. The effects of a wide range of nitrogen application rates on the yields from a perennial ryegrass sward with and without clover. Journal of Agricultural Science 74, 227-240.

Roelofs, J.G.M, A.W. Boxman & H.F.G van Dijk, 1987. Effects of airborne ammonium on natural vegetation and forests. In: Asman, W.A.H. & H.S.M.A Diederen (Eds.). Ammonia and acidification. Proceedings EURASAP Symposium, RIVM, Bilthoven, 266-276.

Rompelberg, L.E.M., H. Wieling & J. Overvest, 1984. Normen voor de voedervoorziening (Standards in Fodder Supply). Publikatie 23, PR, Lelystad, 60 p.

Sawyer,J.E., M.A. Schmitt, R.G. Hoeft, J.C. Siemens & D.H. Vanderholm, 1991. Corn production associated with liquid beaf manure application methods. Journal of Production Agriculture 4, 335-344.

Scholefield, D., D.R. Lockyer, D.C. Whitehead and K. C. Tyson, 1991. A model to predict transformations and losses of nitrogen in UK pastures grazed by beef cattle. Plant and Soil 132, 165-177.

Schröder, J.J., 1991. De benutting van stikstof door maïs met speciale aandacht voor de wortels (The utilization of nitrogen by corn with special attention for the roots). Verslag 152, CABO-DLO, 53 p.

Schröder, J.J. & K. Dilz, 1987. Cattle slurry and farmyard manure as fertilizers for forage maize. In: Meer, H.G. van der, R.J. Unwin, T.A. van Dijk & G.C. Ennik (Eds.). Animal manure on Grassland and fodder crops, Martinus Nijhoff Publishers, Dordrecht, 137-156.

Schröder, J.J., W.J.M. de Groot & W. van Dijk, 1992. Nitrogen losses from continuous maize as affected by cover crops. Nitrate and farming systems, Aspects of Applied Biology 30, 317-326.

Schröder, J. & L. ten Holte, 1992. Stikstofbenutting en -verliezen in maïsteeltsystemen (Utilization and losses of nitrogen in maize cultivation systems). In: Meer, H.G. van der & J.H.J. Spiertz (Eds.), Stikstofstromen in agro-ecosystemen. Agrobiologische Thema's 6, CABO-DLO, Wageningen, 71-85.

Sibma, L. & Th. Alberda, 1980. The effect of cutting frequency and nitrogen fertilizer rates on dry matter production, nitrogen uptake and herbage nitrate content. Netherlands Journal of Agricultural Science 28, 243-251.

Sibma, L. & G.C. Ennik, 1988. Ontwikkeling en groei van produktiegras onder Nederlandse omstandigheden (Development and growth of production grass under Dutch conditions). Gewassenreeks 2, PUDOC, Wageningen, 53 p.

Smits, M.C.J., H. Valk, A. Elzing, J.W.H. Huis in t Veld & A. Keen, 1993. Perspectief van beperking van de ammoniakemissie uit melkveestallen door aanpassing van het rantsoen (Prospects for reducing ammonia emission from a cubicle house for dairy cattle by altering the feed). IMAG-DLO rapport 93-31, Instituut voor Mechanisatie, Arbeid en Gebouwen, Wageningen, 38p.

Snijders, P.J.M., J.J. Woldring, J.H. Geurink & H.G. van der Meer, 1987. Stikstofwerking van geïnjecteerde runderdrijfmest op grasland (Nitrogen efficacy of injected cattle slurry on grassland). Rapport 103, Pr, Lelystad, 156 p.

Spiertz, J.H.J & L. Sibma, 1986. Dry matter production and nitrogen utilization in cropping systems with grass, luzerne and maize. 2. Nitrogen yield and utilization. Netherlands Journal of Agricultural Science 34,37-47.

Spitters, C.T.J., H. van Keulen & D.W.G. van Kraalingen, 1989. A simple and universal crop growth simulator: SUCROS87. In: R. Rabbinge, S.A. Ward & H.H. van Laar (Eds.), Simulation and systems management in crop protection.

Spronk, J. & F.R. Veeneklaas, 1982. A feasibility study of economic and environmental scenarios by means of Interactive Multiple Goal Programming. Regional Science and Urban Economy 13, 141-160.

Steenbergen, T. van, 1977. Invloed van grondsoort en jaar op het effekt van stikstofbemesting op de graslandopbrengst (Influence of soil type and year on the effect of N fertilizer application on grass yield). Stikstof, 85, 9-15.

Steenvoorden, J.H.A.M, 1988. Vermindering van stikstofverliezen naar grond- en oppervlaktewater (Reduction of nitrogen losses to ground- and surface water). ICW nota 1849, Instituut voor Cultuurtechniek en Waterhuishouding, Wageningen, 27 p.

Steenvoorden, J.H.A.M., H. Fonck & H.P. Oosterom, 1986. Losses of nitrogen from intensive grassland systems by leaching and surface runoff. In: Meer, H.G. van der, J.C. Ryden & G.C. Ennik (Eds.). Nitrogen fluxes in Intensive Grassland Systems. Developments in Plant and Soil Sciences no 23, Martinus Nijhoff Publishers, The Hague, 85-97.

Stouthart, F. & J. Leferink (Eds.), 1992. Werkboek Mineralenbenutting Akkerbouw (Workbook utilization of minerals in arable farming). Ministerie LNV, IKC-AGV, DVL, CLM, Lelystad, 95 p.

Tamminga, S., W.M. van Straalen, A.P.J. Subnel, R.G.M. Meijer, A. Steg, C.J.G. Wever & M.C. Blok, 1995. The Dutch protein evaluation system: the DVE/OEB-system. Livestock Prod. Sci.

Veeneklaas, F.R., 1990. Dovetailing technical and economic analysis. Proefschrift Rotterdam, Rotterdam, 159 p.

Ven, G.W.J. van de, 1992. GRASMOD, a grassland management model to calculate nitrogen losses from grassland. Verslag 158, CABO-DLO, Wageningen, 109 p.

Verberne, E., 1992. Simulation of the nitrogen and water balance in a system of grassland and soil. Nota 258, IB-DLO, Haren, 56 p.

Vereijken, P., 1992. A methodic way to more sustainable farming systems. Netherlands Journal of Agricultural Science 40, 209-.

Vertregt, N. & B. Rutgers, 1988. Ammonia volatilization from grazed pastures. Dutch Priority Programme on Acidification, Report 64-2, 37 p.

Voorburg. J.H. and W. Kroodsma, 1992. Volatile emissions of housing systems for cattle. Livestock Production Science, 31, 57-70.

Vries, C. de, 1995. De weide- en voederbouw in bedrijfsverband (Cultivation of grass and fodder crops at farm level). In: Aarts, H.F.M. (Ed.), Weide- en voederbouw op De Marke: op zoek naar de balans tussen produktie en emissie. Rapport nr. 12, De Marke, Hengelo (Gld), 77-89.

Vuuren, A.M. van & 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: Meer, H.G. van der, R.J. Unwin, T.A. van Dijk & G.C. Ennik (Eds.). Animal manure on grassland and fodder crops. Fertilizer or waste?, Martinus Nijhoff, Dordrecht, 17-25.

Vuuren, A.M. van, C.J. van der Koelen, H. Valk & H. de Visser, 1993. Effects of partial replacement of ryegrass by low protein feeds on rumen fermentation and nitrogen loss by dairy cows. Journal of Dairy Science 76, 2982-2993.

Vuuren, A. M. van, S. Tamminga & R.S. Ketelaar, 1991. In sacco degradation of organic matter and crude protein of fresh grass (Lolium perenne) in the rumen of grazing dairy cows. Journal of Agricultural Science (Cambridge) 116, 429-436.

Wadman, W.P. (Ed.), 1988. Mestinjectie: Mogelijkheden, voordelen en problemen (Slurry injection: possibilities, advantages and problems). Verslag van de Werkgroep Mestinjectie, Onderzoek Inzake de Mest- en Ammoniakproblematiek in de Veehouderij I, DLO, Wageningen, 64 p.

Westerdijk, C.E., 1992. Effect van gedeelde bemesting en/of slow-release-bemesting op efficiency/ recovery van de N-bemesting bij suikerbieten (The influence op split application and/or use of slow-release nitrogen fertilizer on the efficiency and recovery of nitrogen in a sugar beet crop). Jaarboek 1991/1992, verslagen van in 1991/1992 afgesloten onderzoeksprojecten op Regionale Onderzoekscentra en het PAGV, Publikatie nr. 64, PAGV, Lelystad, 68-72.

Westhoek, H. & G.J. Noij, 1992. Werking van dierlijke mest op grasland (Effect of animal manure on grassland). RSP-bulletin 1, 10-17.

Whitehead, D.C., 1986. Sources and transformation of organic nitrogen in intensively managed grassland soils. In: Meer, H.G. van der, Ryden & G.C. Ennik (Eds.), Nitrogen fluxes in intensive grassland systems. Nijhoff, Dordrecht, 47-58.

Whitehead, D.C. & K.P. Dawson, 1984. Nitrogen, including 15-N-labelled fertiliser nitrogen, in components of a grass sward. Journal of Applied Ecology 21, 983-989.

Whitehead, D.C. & N Raistrick, 1993. The volatilization of ammonia from cattle urine applied to soils as influenced by soil properties. Plant and Soil 148, 43-51.

Whitmore, A.P. & J.J. Schröder, in prep. Stikstofmineralisatie op maïspercelen: een modelmatige benadering (Nitrogen mineralization on maize fields: a model approach). Rapport AB-DLO.

Wieringa, G.W., 1978. Influence of N fertilizer and cutting frequency on the extraction of protein from grass. 7th General Meeting of the European Grassland Federation, Gent, 6.63-6.68.

Winkel, K. de, 1988. Ammoniak emissiefactoren voor de melkveehouderij (Ammonia emission factors in dairy faming). Lucht 67, 60 p.

Wit, C.T. de, 1988. Environmental impact of the CAP. European Research Agricultural Ecology 15, 283-296.

Wit, C.T. de, 1953. A physical theory on placement of fertilizers. Proefschrift Landbouwhogeschool, Wageningen, 71 p.

Wit, C.T. de, H. van Keulen, N.G. Seligman & I. Spharim, 1988. Application of Interactive Multiple Goal Programming Techniques for analysis and planning of agricultural development. Agricultural Systems 26, 211-230.

Wolf, J., C.T. de Wit & H. van Keulen, 1989. Modelling long-term crop response to fertilizer and soil nitrogen. I. Model description and application. Plant and Soil 120, 11-22.

Wolf, J. & H. van Keulen, 1989. Modelling lang-term crop response to fertilizer and soil nitrogen. II. Comparison with field experiments. Plant and Soil 120, 23-38.

Working Group for Standards in Fodder Supply (Werkgroep Normen voor de Voedervoorziening), 1991. Normen voor de voedervoorziening (Standards in Fodder Supply). Publikatie 70, PR, Lelystad, 63 p.

Wossink, A., 1993. Analysis of future agricultural change, a farm economics approach applied to Dutch arable farming. Proefschrift Landbouwuniversiteit, Wageningen, 220 p.

Zee, S.E.A.T.M. van der, W.H. van Riemsdijk & F.A.M. de Haan, 1990. Het protocol fosfaatverzadigde gronden (The protocol for phosphate satured soils). Vakgroep Bodemkunde en Plantevoeding, Landbouwuniversiteit, Wageningen.

Summary

Introduction

Standard production techniques in Dutch dairy farming are characterized by a high degree of intensification, ample inputs of nutrients, especially nitrogen (N) and phosphorus (P), and a one-sided focus on economic goals. This has resulted in excess production of milk and meat and in environmental pollution. In 1992/93 the N surplus on the nutrient balance of specialized Dutch dairy farms (i.e. the difference between N input and N output at farm level) was on average 406 kg N ha^{-1} and the P surplus 29 kg ha^{-1}. The N surplus, if not accumulated in the soil or denitrified to elementary N, is a source of environmental pollution in the form of nitrate leaching, dinitrogen oxide emission and ammonia volatilization. P accumulates in the soil until it is saturated and then leaches to ground- and surface-waters. The problems are largest on sandy soils, as these are most susceptible to leaching of nitrate and phosphorus and ammonia volatilization. This pollution is no longer accepted by society and the government aims at a reduction by setting restrictions on the various emission processes.

The aim of this study was to explore which dairy farming systems achieve both environmental and economic goals at a satisfactory level.

Approach

The problem was formulated mathematically as an optimization problem with multiple goals. Interactive multiple goal linear programming (IMGLP) is used as optimization technique. IMGLP is a multi-criteria decision method combined with linear programming. A technical analysis is combined with economic data to gain a better insight in the possibilities for development of dairy farming on sandy soils than would be achieved by disciplinary research. Interested parties are requested to explicitly state their goals in dairy farming. The goals are expressed in their own unit, which makes it possible to establish the trade-offs between them. In an interactive procedure, the parties are confronted with the consequences of their views. This procedure consists of various optimization rounds, in which the goals are optimized, under increasingly tight restrictions on the other goals. Behavioural relations are not included to prevent that possible technical developments are obscured in advance. The model is not dynamic in time, but presents the end of a development path. The results describe possible scenarios and do not predict future developments.

Application of IMGLP requires a consistent set of input-output coefficients, describing the contribution of a wide range of production techniques to the goals and restrictions defined. To quantify the input-output coefficients in a systematic and consistent way Technical Coefficient Generators (TCG models) were developed for cultivation of grass (GRASMOD), maize and fodder beets. The data generated by the TCG models were linked to the IMGLP model. The TCG and IMGLP models together form the Dairy Farming Model.

The main characteristics of the grass production techniques are: grassland utilization method (zero-grazing, day-and-night grazing, day grazing and cutting for conservation), N application rate (8 rates, ranging from 100 to 450 kg N ha^{-1} yr^{-1}) and stocking rate, as determined by supplementation with concentrates (3 concentrate feeding levels). Maize can be grown continuously or in rotation with fodder beets. The main characteristics of the maize production techniques are production level and product quality, the ratio of slurry:artificial fertilizer N in the N supply to the crop, slurry application method and cultivation of a catch crop. Similar characteristics apply to fodder beets. Animal production techniques are characterized by cattle type (dairy cow, calf, yearling) and milk production level (5 000, 6 500, 8 000 kg milk cow^{-1} yr^{-1}). Each feasible combination of characteristics represents one production technique. The dairy farming system consists of a set of production techniques.

The production techniques were quantified in terms of required inputs and intended and unintended outputs. The main inputs to the crop production techniques are slurry, artificial fertilizer, land, labour and costs. The main outputs are forage of a specified quality, expressed in energy value and protein and P content, nitrate leaching and ammonia volatilization. The main inputs to the animal production techniques are forage of a specified quality, concentrates, labour and costs. The main outputs are milk, meat, manure, ammonia volatilization and income. Quantification of the technical coefficients was based on results from field experiments, literature data and expert consultation and focused on attainable yield levels. The model applies to well-drained sandy soils.

The results of this study apply to a large efficiently managed farm, and scale effects are not considered. The aim was to get an indication of the economic consequences of technical and environmental measures, not to make a detailed farm-economic analysis. Capital costs, which are generally fixed costs at farm level, were attributed to cropping and animal production techniques and hence, converted to variable costs. The economic results can thus not directly be translated to labour income or net result at farm level.

The optimization matrix consists of a set of goals, activities (e.g. production techniques) and constraints. The activities were classified in cropping activities, feeding activities, cattle production activities, activities describing the N and P flows via slurry to crops and losses and purchase and sale activities. The constraints link the crop production techniques via feeding activities to the animal production techniques. They ensure that energy and protein requirements of the cattle are met. They also describe N and P flows from the animals via slurry to the crops. Roughage has to be produced on the available land and all slurry has to be applied to prevent shifting of the associated N and P losses to other areas.

Results

The Dairy Farming model was applied at regional and at farm scale. Three scenarios were explored. The first scenario represents dairy farming according to the nitrogen policy objectives as laid down by the government for the year 2000. The second scenario also includes other objectives. For the third scenario the model was adapted to the situation at the experimental farm 'De Marke' and optimization results were confronted with the design and results obtained in practice.

Dairy farming in the year 2000

The goals considered were nitrate leaching, ammonia volatilization and labour income. With no restrictions on any of these goals, maximum labour income was Dfl 5 250. In that situation a milk production of 26 t ha^{-1} can be achieved, if zero grazing is practised and 13 t concentrates per ha are purchased. No maize and fodder beets are grown and the stocking rate is 3.3 cows ha^{-1}. This is the most intensive system possible under the defined set of production techniques and constraints.
According to the nitrogen policy objectives as laid down by the government for the year 2000, the target value for nitrate leaching is set to 34 kg N ha^{-1} and for ammonia volatilization to 30 kg N ha^{-1}. This results in a maximum attainable income of Dfl 3 810 ha^{-1} yr^{-1}. The shadow prices for nitrate leaching and ammonia volatilization were respectively, Dfl 4 and 57 kg^{-1} N. Hence measures to reduce ammonia volatilization to its target value are more expensive than those for nitrate leaching. The selected dairy farming system has 85 % of the area in grass and 15 % in maize. Cows are outside during the day only and are supplemented with maize during the night. N application rate on grassland is 170 kg ha^{-1}. The stocking rate is 2.1 cows with the associated young stock ha^{-1}. Milk production is 16.4 t ha^{-1} and 5.5 t concentrates ha^{-1} are purchased.
Reducing N losses to the levels aimed at for the year 2000 leads to extensification of dairy farming, when compared to the optimization results

obtained without any restrictions. Milk production is still rather high compared to commercial farms, but these are limited by milk quota, which have not been taken into account in the calculations. The main differences between this dairy farming system and that aimed at maximum labour income without restrictions are N application rate on grassland, the grassland utilization system, stocking rate, concentrate purchases, low-emission constructions and the area under maize. The policy objectives for the year 2000 can be achieved if a 28 % reduction in labour income is accepted. Most of this reduction is associated with the restriction on volatilization.

Integrated dairy farming on sandy soils

In this study, goals concerning economics, environment and landscape were defined for integrated dairy farming: nitrate leaching, ammonia volatilization, N surplus, P surplus, milk production per ha, labour income, net result (i.e. a remuneration for entrepreneurship), cattle outside in summer and an area reserved for wooded banks. In 12 optimization rounds, target values for these goals were set to 34 kg N ha^{-1}, 30 kg N ha^{-1}, 130 kg N ha^{-1}, 2.2 kg P ha^{-1}, 10.0-12.5 t ha^{-1}, Dfl 0 ha^{-1}, Dfl 0 ha^{-1}, 1 cow ha^{-1} and 5 % of the available area, respectively. The results and the trade-offs between goals are described in Chapter 6. Meeting all restrictions still leaves some space for realization of individual goals.

The dairy farming system selected under optimization of nitrate leaching, ammonia volatilization, P surplus and net result are discussed. The economic and environmental performance of the scenarios for minimum nitrate leaching and minimum ammonia volatilization are similar. Hence, these goals are not conflicting, although there are considerable differences between the selected dairy farming systems (Subsection 6.3.3). Labour income per tonne milk is 65 % of that achieved when maximizing the net result. Milk production per kg P input is 63 % of that when minimizing P surplus. In the scenario with a minimum P surplus the net result is 62 % of that under maximum net result.

Within the accepted area, i.e. the part of the solution area where each combination of goal variable is acceptable to each of the interested parties, many different dairy farming systems are possible. It depends on preferences of the model user which scenario is selected. The major general characteristics are: low N application rates on grazed grassland associated with the restriction on nitrate leaching, a large proportion of the animals housed in low-emission stables associated with the restriction on ammonia volatilization, and a substantial part of the concentrates produced in the region associated with the restriction on P surplus.

Dairy farming at the experimental farm 'De Marke'

At the experimental dairy farm 'De Marke' a dairy farming system is developed that at least meets the environmental objectives for the year 2000. In Chapter 7, first, the parameters and relationships used in the model were adapted to the situation at 'De Marke' and subsequently, the present system was simulated. In general the results agree reasonably will with the actual results from 'De Marke'. This offers an opportunity to evaluate that system and the scope for further improvements.

Next, dairy farming for the situation prevailing at 'De Marke' was optimized. Restrictions were set on nitrate leaching ($\leq$ 34 kg N ha^{-1} yr^{-1}), ammonia volatilization ($\leq$ 30 kg N ha^{-1} yr^{-1}), P surplus ($\leq$ 0.5 kg ha^{-1} yr^{-1}) and labour income was maximized. Maximum labour income is Dfl 4 380. According to the model all land is in grass, cows are outside day and night, milk production is 15.4 t ha^{-1} and the stocking rate is 1.62 dairy cows with the associated young stock ha^{-1}. Currently, at 30 % of the area 'De Marke' is in maize, 10 % in fodder beets and 60 % in grass, cows are outside during the day only and supplemented with maize at night, milk production is 12 t ha^{-1} and the stocking rate is 1.44 cows ha^{-1}.

The discrepancy between model results and the current system is to a large extent due to the absence of a restriction on N surplus of 128 kg ha^{-1} in the model. This was not set, as it can not be established accurately. It is debatable whether N surplus should be a specific goal at this moment. More detailed research is needed to improve existing knowledge on environmental factors and the processes determining accumulation and denitrification.

The effect of measures taken at 'De Marke' were evaluated (Chapter 7). Cultivation of concentrate replacing crops on-farm appeared to be costly and reduced total milk production. Only if the milk quota of a farm is below the calculated one, there is some scope for concentrate replacing crops. Drying grass artificially is then a serious option.

Further adaptation of the Dairy Farming Model to the situation at 'De Marke' will improve its value in guiding development of the farm lay-out and management. Additional research on specific topics, such as mineralization rate under grassland, the long-term effects of low P application rates, division of P over crops in rotation and the feeding standards for highly productive cows is required to improve model results and translation of the results obtained at 'De Marke' to other situations.

Conclusion

The analysis in this study shows that Dutch dairy farming on sandy soils can meet both economic and environmental goals at the same time. This, however, requires a reduction in labour income and acceptance of a certain N emission level.
The set of models developed in this study offers a good opportunity for making the consequences of policy goals and measures explicit. The Dairy Farming Model can be used to identify the conditions required for selection of specific production techniques and to assess the potentials of new production techniques. Gaps in knowledge are revealed. New issues with regard to process oriented experimental research and to further refinement and extension of the Dairy Farming Model are given.

Samenvatting

Inleiding

De gangbare produktietechnieken in de Nederlandse melkveehouderij worden gekenmerkt door een hoge mate van intensivering, een ruime inzet van nutriënten, met name stikstof (N) en fosfor (P), en een eenzijdige nadruk op economische doelen. Dit heeft geleid tot overproduktie van melk en vlees en tot milieuvervuiling. In 1992/93 was het N-overschot op de mineralenbalans van gespecialiseerde melkveebedrijven (dit is het verschil tussen N aanvoer en N afvoer op bedrijfsniveau) gemiddeld 406 kg ha^{-1} en het P-overschot 29 kg ha^{-1}. Het N-overschot, voor zover het niet ophoopt in de bodem of denitrificeert tot stikstofgas, spoelt uit als nitraat en vervluchtigt als ammoniak en lachgas. P hoopt zich op in de bodem tot deze verzadigd is en spoelt dan uit naar grond- en oppervlaktewateren. De milieuproblemen zijn het grootst op zandgronden. Deze milieuvervuiling wordt niet langer geaccepteerd door de maatschappij. De overheid heeft hierop gereageerd door normen op te stellen voor de verschillende vormen van emissie.
Het doel van deze studie was mogelijke ontwikkelingsrichtingen voor melkveehouderij op zandgrond te identificeren die zowel aan economische als milieu- en landschap doelen tegemoet komen.

Methode

Het probleem is wiskundig geformuleerd als een optimaliseringsprobleem met meerdere doelen. Als optimaliseringstechniek is Interactieve Meervoudige Doelprogrammering gebruikt (IMDP). IMDP is een multi-criteria optimaliseringstechniek gecombineerd met lineaire programmering. Een technische analyse is gecombineerd met economische gegevens om een beter inzicht in mogelijke ontwikkelingen voor melkveehouderij te krijgen, dan zou worden verkregen bij disciplinair onderzoek. Groeperingen met verschillende belangen worden gevraagd hun doelen aangaande de melkveehouderij expliciet te formuleren. In een interactieve procedure worden deze belangengroepen geconfronteerd met de consequenties ervan. Elk doel wordt uitgedrukt in zijn eigen eenheden, wat het mogelijk maakt uitruilwaarden vast te stellen. De procedure bestaat uit verschillende ronden, waarin elk doel wordt geoptimaliseerd onder steeds stringentere beperkingen op de overige doelen. Gedragsrelaties worden niet meegenomen. Het model is statisch en beschrijft het eind van een ontwikkelingspad. Het schetst mogelijke scenario's en kan niet gebruikt worden voor toekomstvoorspellingen.

Toepassing van IMDP vraagt om een set input-ouput coëfficiënten, die de bijdrage van een groot aantal uiteenlopende produktietechieken aan het realiseren van doelen en beperkingen beschrijft. Om deze systematisch te kwantificeren zijn Technische Coëfficiënten Generators (TCG's) ontwikkeld voor de teelt van gras (GRASMOD), maïs en voederbieten. De resultaten van de TCG's zijn gekoppeld aan het IMDP-model. Tezamen vormen deze submodellen het Melkveehouderijmodel.

De grasproduktietechnieken worden gekenmerkt door: de graslandgebruikswijze (onbeperkt omweiden, beperkt omweiden, zomerstalvoedering, maaien voor conservering van wintervoer), N-bemestingsniveau (100-450 kg ha^{-1}) en de veebezetting (afhankelijk van krachtvoerbijvoeding). Maïs kan worden verbouwd in continuteelt of in rotatie met voederbieten. Maïs- en voederbietproduktietechnieken variëren in opbrengst en produktkwaliteit, de verhouding waarin kunstmest en drijfmest aangewend worden, de methode van drijfmesttoediening en het al of niet telen van een vanggewas. Dierlijke produktietechnieken worden bepaald door de diersoort (koe, pink, kalf) en de melkproduktie (5 000, 6 500, 8 000 kg koe^{-1} jr^{-1}). Elke realistische combinatie van de genoemde kenmerken beschrijft één produktietechniek. Een set plantaardige en dierlijke produktietechnieken beschrijft het melkveehouderijsysteem.

De belangrijkste inputs voor de gewasproduktietechnieken zijn drijfmest, kunstmest, land, arbeid en kosten. De belangrijkste outputs zijn veevoer van een bepaalde kwaliteit, nitraatuitspoeling en ammoniakvervluchtiging. Voor de dierlijke produktietechnieken zijn de belangrijkste inputs ruwvoer van een bepaalde kwaliteit, krachtvoer, arbeid en kosten. Outputs zijn melk en vlees, drijfmest, ammoniakvervluchtiging en geld. Kwantificering van de technische coëfficiënten is gebaseerd op gegevens van veldproeven, literatuur en deskundigen. De aandacht was gericht op kwantificering van haalbare produktieniveaus op goed ontwaterde zandgronden in Nederland.

De resultaten van deze studie zijn van toepassing op een groot efficiënt melkveebedrijf en schaaleffecten zijn buiten beschouwing gelaten. Het doel was een indicatie te verkrijgen van de economische gevolgen van technische en milieu-maatregelen en niet om een gedetailleerde bedrijfseconomische analyse te maken. Kapitaalkosten, op bedrijfsniveau in het algemeen vaste kosten, zijn toegerekend aan land en dieren en zodoende omgezet in variabele kosten. De economische resultaten van het model kunnen dus niet zonder meer vertaald worden naar inkomen op bedrijfsniveau.

De optimaliseringsmatrix bestaat uit een aantal doelen, activiteiten (o.a. de dierlijke en plantaardige produktietechnieken) en beperkingen. De activiteiten omvatten gewasproduktieactiviteiten, voederingsactiviteiten, activiteiten voor melk- en vleesproduktie, activiteiten die de N- en P-stromen beschrijven en aan- en verkoopactiviteiten. De beperkingen verbinden de gewasproduktieactiviteiten met de dierproduktieactiviteiten. Ze zorgen ervoor dat in energie- en eiwitbehoefte van het vee voorzien wordt en beschrijven N- en P-stromen van de dieren via drijfmest naar de gewassen. Alle ruwvoer moet op het beschikbare areaal worden verbouwd om afwenteling van N- en P-verliezen te voorkomen.

Resultaten

Het melkveehouderijmodel is toegepast op regionaal en bedrijfsniveau. Drie verkenningen zijn uitgevoerd. Het eerste scenario beschrijft de mogelijkheden voor melkveehouderij in 2000 onder de overheidsbeperkingen betreffende N-emissies. In het tweede scenario zijn ook P- en landschapsdoelen betrokken. Voor het derde scenario is het model geïnitialiseerd voor de situatie op de proefboerderij 'De Marke' en zijn modelresultaten vergeleken met de bedrijfsopzet en resultaten zoals in de praktijk behaald.

Melkveehouderij in 2000

Drie doelen zijn tegen elkaar afgewogen: nitraatuitspoeling, ammoniak-vervluchtiging en arbeidsinkomen. Bij maximalisering van het inkomen zonder enige beperkingen op stikstofemissies kan een melkproduktie van 26 t ha^{-1} bereikt worden. Daar hoort zomerstalvoedering bij met krachtvoeraankopen van ruim 13 t ha^{-1} en een inkomen van fl 5 250 ha^{-1}. Maïs en voederbieten worden niet geteeld en de veebezetting is 3.3 koeien ha^{-1}. Dit is het meest intensieve systeem dat onder de gegeven set van produktiesystemen en randvoorwaarden mogelijk is.

De emissienormen voor 2000 zijn voor nitraatuitspoeling vertaald in 34 kg N ha^{-1} jr^{-1} en voor ammoniakvervluchtiging in 30 kg N ha^{-1} jr^{-1}. Dit heeft tot gevolg dat het maximaal haalbare inkomen daalt naar fl 3 810. De schaduw-prijzen voor uitspoeling en vervluchtiging zijn respectievelijk fl 4 en fl 57 per kg N. Dit betekent dat maatregelen om de ammoniakemissie te reduceren tot de norm veel duurder zijn dan die voor nitraatuitspoeling. In het geselecteerde melkveehouderijsysteem ligt 85 % van het areaal in gras en 15 % in maïs. De melkkoeien worden beperkt omgeweid en krijgen 's nachts maïs bijgevoerd. De gemiddelde N-gift op grasland is 170 kg ha^{-1}. De veebezetting is 2,1 koeien per ha, melkproduktie is 16,4 t ha^{-1} en er wordt 5 ,5 t krachtvoer per ha aangekocht.

Reduceren van de N-emissie tot de normen voor het jaar 2000 leidt tot extensivering van de melkveehouderij ten opzichte van de situatie zonder beperkingen. De melkproduktie is nog steeds hoog ten opzicht van de gangbare produktie op zandgrond, maar deze wordt beperkt door de melkquotering. In de berekeningen is het melkquotum geen beperking. De grootste verschillen tussen de geselecteerde melkveehouderijsystemen met en zonder beperkingen zijn de N-bemesting op gras, de graslandgebruikswijze, de veebezetting, de krachtvoer-aankoop, type stal en mestopslag en het areaal maïs. De normen voor 2000 kunnen worden gehaald als een reductie in het arbeidsinkomen van 28 % acceptabel is.

Geïntegreerde melkveehouderij

De volgende doelstellingen voor geïntegreerde melkveehouderij zijn geoptimaliseerd: nitraatuitspoeling, ammoniakvervluchtiging, N-overschot, P-overschot, melkproduktie per ha, arbeidsinkomen, ondernemersinkomen, aantal koeien buiten in de zomer en een oppervlak gereserveerd voor houtwallen en natuurontwikkeling. In 12 optimaliseringsronden zijn de volgende beperkingen op deze doelen gezet, respectievelijk: 34 kg N ha^{-1}, 30 kg N ha^{-1}, 130 kg N ha^{-1}, 2,2 kg P ha^{-1}, 10-12,5 t ha^{-1}, fl 0 ha^{-1}, fl 0 ha^{-1}, 1 koe ha^{-1}, en 5 % van het beschikbare oppervlak. De resultaten en de uitruilwaarden tussen de doelen zijn in hoofdstuk 6 beschreven.
Het melkveehouderijsysteem geselecteerd bij optimalisering van nitraatuitspoeling, ammoniakvervluchtiging, P-overschot en ondernemersinkomen wordt besproken. De economische en de milieuprestatie van de melkveehouderij zijn vergelijkbaar bij minimale nitraatuitspoeling en minimale ammoniak-vervluchtiging. Deze doelstellingen zijn dus weinig conflicterend, maar de geselecteerde produktietechnieken verschillen aanzienlijk. Het arbeidsinkomen per ton melk is 65 % van dat wat bereikt wordt bij een maximaal ondernemersinkomen. De melkproduktie per kg P input is 63 % van die bij minimalisering van het P-overschot. Bij minimalisering van het P-overschot is het ondernemersinkomen 62 % van dat behaald bij maximalisering ervan.
De geaccepteerde oplossingsruimte, dit is dat deel van de oplossingsruimte waarbinnen elke combinatie van de waarden van doelstellingen acceptabel is voor elke belangengroep, laat een breed scala aan melkveehouderijsystemen toe. De belangengroep bepaalt welk scenario uiteindelijk gekozen wordt. Een paar gemeenschappelijke kenmerken van de systemen zijn: een lage N-bemesting op beweid grasland door de restrictie op nitraatuitspoeling, emissiearme stallen en mestopslag door de restrictie op ammoniakvervluchtiging en een aanzienlijke eigen teelt van krachtvoer door de restrictie op P-surplus.

Melkveehouderij op proefboerderij 'De Marke'

Op de proefboerderij 'De Marke' wordt een melkveehouderijsysteem ontwikkeld dat ten minste voldoet aan de emissienormen voor 2000. In hoofdstuk 7 is getoetst of het Melkveehouderijmodel, geïnitialiseerd voor de omstandigheden op 'De Marke' realistische resultaten geeft en of de bedrijfsopzet en de maatregelen genomen om de gestelde doelen te bereiken doeltreffend zijn.

De parameters en relaties gebruikt in het Melkveehouderijmodel zijn aangepast aan de omstandigheden op 'De Marke' en vervolgens is het huidige melkveeehouderijsysteem gesimuleerd. Over het algemeen komen de modeluitkomsten redelijk goed overeen met de praktijkresultaten. Dit biedt de mogelijkheid om het melkveehouderijsysteem op 'De Marke' te evalueren.

Voor de omstandigheden op 'De Marke' is het arbeidsinkomen gemaximaliseerd onder beperkingen op nitraatuitspoeling (≤ 34 kg N ha^{-1} jr^{-1}), ammoniakvervluchtiging (≤ 30 kg N ha^{-1} jr^{-1}) en P-overschot (≤ 0,5 kg P ha^{-1} jr^{-1}). Het maximale arbeidsinkomen is fl 4 380 ha^{-1}. In het door het model geselecteerde melkveehouderijsysteem ligt het hele bedrijf in grasland, koeien worden onbeperkt geweid, de melkproduktie is 15,4 t ha^{-1} en de veebezetting is 1,62 melkkoeien met bijbehorend jongvee per ha. Momenteel wordt op 'De Marke' op 30 % van het areaal maïs geteeld, op 10 % voederbieten en op 60 % gras, koeien worden beperkt geweid, de melkproduktie is 12 t ha^{-1} en de veebezetting 1,44 koeien ha^{-1}.

Het verschil tussen modeluitkomsten en de praktijk wordt in belangrijke mate veroorzaakt door de afwezigheid van een beperking op het N-overschot van 128 kg ha^{-1} in het model. Het is moeilijk een goed onderbouwde norm voor het N-overschot vast te stellen. Hiervoor is meer onderzoek nodig aangaande factoren en processen die ophoping en denitrificatie beïnvloeden.

Het effect van maatregelen genomen op 'De Marke' is geëvalueerd (Hoofdstuk 7). Verbouw van eigen krachtvoer blijkt duur te zijn en legt een druk op de melkproduktie. Het is alleen rendabel om eigen krachtvoer te telen, indien het melkquotum lager is dan het berekende en er dus grond over is. Kunstmatig drogen van gras is in dat geval een serieuze optie.

Door verdere aanpassingen van het Melkveehouderijmodel aan de omstandigheden op 'De Marke', wordt het meer geschikt om ontwikkeling van de bedrijfsopzet en management te begeleiden. Extra onderzoek, zoals naar de mineralisatie van N onder grasland, lange termijn effecten van lage P-bemestingsniveaus, bouwplanbemesting met P en de veevoedingsnormen voor hoog produktief melkvee, is nodig om model resultaten te verbeteren en extrapolatie van het systeem ontwikkeld op 'De Marke' naar andere omstandigheden mogelijk te maken.

Conclusies

De analyse in deze studie laat zien dat de Nederlandse melkveehouderij op zandgrond zowel aan economische als aan milieudoelen tegemoet kan komen. Om aan beide tegelijkertijd in redelijke mate te voldoen moet echter zowel inkomen worden opgeofferd als een hoeveelheid stikstofemissie worden geaccepteerd.
De set van modellen die in deze studie is ontwikkeld biedt goede mogelijkheden om gevolgen van overheidsdoelen en maatregelen expliciet te maken. Het Melkveehouderijmodel kan gebruikt worden om te verkennen onder welke omstandigheden bepaalde produktietechnieken geselecteerd worden en om de potenties van nieuwe produktietechnieken vast te stellen. Leemten in kennis worden duidelijk zichtbaar gemaakt. Een aanzet voor procesgeoriënteerd onderzoek en uitbreiding en verfijning van het model wordt gegeven.

Appendix A

List of acronyms LP-model

Indices:

A: method to apply slurry

1. deep injection
2. injection with open slits/ploughing after application
3. surface spreading

B: grassland utilization method

1. zero grazing, no supply of maize silage
2. zero grazing, supply of maize silage
3. day-and-night grazing, no supply maize silage
4. day grazing, supply of maize silage

C: herbage supply

1. maximum herbage intake
2. 0.9 of the maximum herbage intake, extra concentrates
3. 0.8 of maximum herbage intake, extra concentrates

F: conserved grass, consumed in winter

1. hay, harvested at 4000 kg DM ha^{-1}
2. grass silage, harvested at 4000 kg DM ha^{-1}
3. grass silage, harvested at 3000 kg DM ha^{-1}
4. artificially dried grass, harvested at 3000 kg DM ha^{-1}

G: number of crop types

1. grass consumed fresh in summer
2. conserved grass, consumed in winter
3. maize
4. fodder beet

L: treatment of fodder beet leaves

1. leaves are left in the field
2. leaves are harvested

M: milk production levels

1. no milk (young stock)
2. 5000 kg per cow per year
3. 6500 kg per cow per year
4. 8000 kg per cow per year

N: fertilizer application rates

	grass kg N $ha^{-1}yr^{-1}$	maize + fodder beet % inorganic N fertilizer
1	100	100
2	150	75
3	200	50
4	250	0
5	300	-
6	350	-
7	400	-
8	450	-

P: periods in a year

1. summer
2. winter

Q: type of maize products

1. silage maize
2. ground ear silage

R: method of fertilization

1. broadcasting both inorganic fertilizer and slurry
2. banded placement of inorganic fertilizer
3. banded placement of slurry
4. banded placement of both inorganic fertilizer and slurry

S: production level and product quality

S	Maize		Fodder beet	
	DM yield $t\ ha^{-1}yr^{-1}$	N content $g\ kg^{-1}$	DM yield $t\ ha^{-1}yr^{-1}$	N uptake $kg\ ha^{-1}$
1	14.3	13	22	265
2	13.7	12	-	-
3	12.7	11	-	-

T: concentrate type

1. protein poor (14.7 g N kg^{-1})
2. standard (23 g N kg^{-1})
3. moderately protein poor (20 g N kg^{-1})
4. protein rich (32 g N kg^{-1})
5. very protein rich (64 g N kg^{-1})
6. P poor (23 g N kg^{-1})

W: catch crop under maize in winter time

1. no catch crop
2. growing a catch crop

Y: type of cattle

1. dairy cows (> 2 years)
2. calves (0-1 year old)
3. yearlings (1-2 year old)

Z: type of stable and storage

1. current type
2. storage covered, stable adapted to low ammonia emissions

Activities

XAREA	Area available for crop cultivation [ha]
XB(S,N,A,R,L,W,Q)	Rotation of fodder beet and maize with production level and product quality S, percentage of inorganic fertilizer N, slurry application method A, percentage of inorganic fertilizer N, fertilizer application method R, fate of fodder beet leaves L, presence of a winter crop after maize W and maize product Q [ha]
XBVB(S,Y,M,Z)	Feeding fodder beet with product quality S to cattle type Y with milk production level M in stable and storage type Z [kg]
XBVL(S,Y,M,Z)	Feeding beet leaves with product quality S to cattle type Y with milk production level M in stable and storage type Z [kg]
XC(T)	Total use of concentrates type T [kg]
XC(T,P,Y,M,Z)	Feeding concentrate type T in period P to cattle type Y with milk production level M in stable and storage type Z [kg]
XCCL	Total costs of hiring contract labour [Dfl]
XCONC(Y,M,Z)	Total concentrate intake by cattle type Y with milk production level M in stable and storage type Z [kg]
XDMIW(Y,M,Z)	Total dry matter intake by cattle type Y with milk production level M in stable and storage type Z [kg]
XF(F,N)	Production technique for conserved herbage type F with fertilizer application level N [ha]
XFIXC	Total fixed costs [Dfl]
XFLN	N in feeding losses in the stable [kg N]
XFV(F,N,Y,M,Z)	Feeding of conserved grass type F produced at fertilizer level N to cattle type Y with milk production level M in stable and storage type Z [kg]
XG(Y,B,N,C,M)	Grass production technique for cattle type Y with grassland utilization method B, fertilizer application level N, herbage supply level C and milk production level M [ha]
XINC	Labour income [Dfl]
XKFER(G)	Inorganic K fertilizer application per crop type G [kg K]
XLAB	Total regional labour input [h]
XLSA	Number of animals outside in summer for landscape purposes [head]
XLSCL(G)	Area under wooded banks for each crop type G
XLSL	Total area reserved for wooded banks [ha]
XM(S,N,A,R,W,Q)	Maize in continuous cultivation with production level and product quality S, percentage of inorganic fertilizer N, slurry application method A, fertilizer application method R, presence of a winter crop W and type of product Q [ha]
XMILK	Milk production [kg]

XMV(Q,P,S,Y,M,Z)	Feeding maize product Q with quality S in period P to cattle type Y with milk production level M in stable and storage type Z [kg]
XN2OT	Total denitrification [kg N]
XNAVS	N in slurry at the moment of application [kg N]
XNBLF	Organic N balance of grassland used for conservation [kg N]
XNBLG	Organic N balance of grassland used for grazing or zero-grazing [kg N]
XNFER(G)	Inorganic N fertilizer application per crop type G [kg N]
XNH3T	Total ammonia volatilization [kg N]
XNH3S(Y,Z,P)	Ammonia volatilization from cattle type Y in stable and storage type Z in period P [kg N]
XNO3T	Total nitrate leaching [kg N]
XNOV	N surplus [kg N]
XNSL(Y,M,P,Z)	Total amount of N collected in slurry from cattle type Y with milk production level M in period P in stable and storage type Z [kg N]
XNSUM	N balance row [kg N]
XPFER(G)	Inorganic P fertilizer application per crop type G [kg P]
XPOV	P surplus [kg P]
XSALE(Y)	Sale of surplus cattle of type Y due to culling and replacement [head]
XSLA(A,G)	Application of slurry using method A on crop G [kg N]
XVARC	Total variable costs [Dfl]
XYS(Y,B,N,C,M,Z)	Number of cattle type Y kept under grassland utilization method B, with an N application on grassland N, herbage supply level C, milk production level M and stable and storage system Z [head]

Appendix B

Values and sources of technical coefficients not calculated by TCG's

Feeding value of feed components

All characteristics of the various feeds are expressed on a dry matter basis. Literature sources are indicated with numbers between brackets in the tables and listed underneath.

Energy, DVE, OEB and P content in the various feeds.

Feed component		Energy content MJ kg^{-1}	N content g kg^{-1}	DVE content g kg^{-1}	OEB content g kg^{-1}	P content g kg^{-1}	Structure value -
Beet (1)		7.08	8.4	74	51	2.0 (3)	0.0
Beet leaves (2)		6.01	25.1	69	51	3.5 (3)	0.2
Concentrates (1,2):							
1. low protein		7.48	14.7	65	-21	3.2 (3)	0.0
2. standard		7.21	23.0	100	-11	5.0	0.0
3. moderately low protein		7.21	20.0	90	-21	5.0	0.0
4. protein rich		7.21	32.0	133	39	5.5	0.0
5. very protein rich		7.21	62.0	200	138	12.2	0.0
6. low P		7.21	23.0	100	-11	3.5	0.0
Maize(1,4):							
whole plant silage	13 g N kg^{-1}	6.23	13.0	46	-16	2.2 (3)	0.65
	12 g N kg^{-1}	6.23	12.0	43	-21	2.2 (3)	0.65
	11 g N kg^{-1}	6.23	11.0	41	-25	2.2 (3)	0.65
ground ear silage	13 g N kg^{-1}	7.48	13.0	65	-21	3.2 (3)	0.0
	12 g N kg^{-1}	7.48	12.0	62	-26	3.2 (3)	0.0
	11g N kg^{-1}	7.48	11.0	60	-31	3.2 (3)	0.0

(1) Central Bureau for Animal Feeds , 1993

(2) Asijee, 1993

(3) National Reference Centre for Agriculture, 1991

(4) National Reference Centre for Agriculture, 1992

Structural value of conserved grass

Forage type	Structural value
Hay, 4 t DM cut^{-1}	1.0
Grass silage, 4 t DM cut^{-1}	0.9
Grass silage, 3 t DM cut^{-1}	0.8
Artificially dried grass, 3 t DM cut^{-1}	0.0

Conservation and feeding losses

Conservation and feeding losses in percentage of the amount produced or purchased for the various feeds (Asijee, 1993).

Feed	Loss, % of DM
Fodder beets	13
Beet leaves	11
Concentrates	2
Maize silage	10
Ground ear silage	7
Hay*	5
Grass silage*	5
Artificially dried grass*	5

* feeding losses only, harvest losses are accounted for in GRASMOD

Cutting grass for conservation

A minimum cutting percentage of 50 % is set to grassland used in summer for grazing. This implies that at least 10 % of the annual production is used for conservation. Calves graze during only part of the growing season and it assumed that the remainder is cut for conservation. This implies that for every ha grazed by calves, 0.42 ha is cut.

Cutting grass for conservation per ha grazed by the various cattle types

Cattle type	Minimum area cut, ha ha^{-1}
Dairy cow	0.10
Calf	0.42
Yearling	0.10

Feed requirements of animals in winter

Maximum dry matter intake from roughage in winter, the energy and the DVE requirement are calculated according to the Cow Model (Hijink & Meijer, 1987) and the model for young stock (Mandersloot, 1989).

For dairy cows maximum dry matter intake depends on milk production and energy content of the feed. The energy value of grass silage used here is 6.045 MJ kg^{-1}.

The year is divided into five lactation periods, of which three are in winter (Chapter 2). For each lactation period maximum dry matter intake and energy and protein demand are calculated seperately. Subsequently, the weighted average was calculated for the whole winter. The ration of calves from 1 February to 24 May consists of milk, hay and concentrates as specified by Pelser (1988) and is not optimized. The amounts required are produced within the system or purchased. Calves are outside from 25 May to 30 September. Therefore, the winter period for which the ration is optimized, extends from 1 October to 31 January (123 days).

The maximum dry matter intake, energy and protein demand for all animal types in winter.

Animal type	Milk production kg $cow^{-1}yr^{-1}$	Winter days	Maximum DM intake kg $head^{-1}$	Energy demand MJ $head^{-1}$	DVE demand kg $head^{-1}$
Dairy cow	5 000	181	1937	15460	167.7
	6 500	181	2154	17460	204.7
	8 000	181	2353	19400	241.8
Calf		123	701	3981	33.6
Yearling		181	1387	8215	65.5

Landscape

The maximum area occupied by landscape elements, such as wooded banks, is 5 %, identical to that for ecological farming (Kloen, pers.comm.). For a rectangular field of 100 x 200 m this results in a strip of $3^1/_3$ m wide. On this strip the N input consists of deposition only (45 kg ha^{-1} yr^{-1}). The nitrate loss is set equal to the loss under unfertilized grassland, i.e. 13 kg N ha^{-1} yr^{-1}. The remaining 32 kg acumulates in the soil.

Nitrogen and phosphorus parameters

N and P content of animals and N and P incorporation in products in winter (Coppoolse et al., 1990; Asijee, 1993)

Cattle type	N content kg N $head^{-1}$	P content kg P $head^{-1}$
Dairy cow	15.0	4.8
Calf	1.1	0.3
Yearling	7.8	2.5

The N content in milk is 5.3 g kg^{-1}
The P content in milk is 0.9 g kg^{-1} (Coppoolse et al., 1990)

Fate of slurry N under various application methods (Asijee,1993; Westhoek & Noij, 1992)

Crop	Method	Uptake	NH_3 volatilization	Rest
Grass	deep injection	0.60	0.01	0.39
	injection with open slits	0.50	0.06	0.44
	surface spreading	0.32	0.30	0.38
Maize/fodder beets	injectie	0.47	0.025	0.505
	inmediate incorporation	0.40	0.125	0.475
	surface spreading	0.26	0.30	0.44

Ammonia volatilization from stable and storage.

Both in winter and summer cows are inside during part of the day and slurry is collected inside. For the winter period and standard stables De Winkel (1988) calculated N excretion in slurry as the difference between N intake by the animal and incorporation by milk and meat for an average ration (6.7 kg wilted silage, 2.8 kg maize silage and 5.7 kg concentrates). The difference between the amount of N excreted and the amount in slurry at the moment of application was attributed to ammonia volatilization. This was 8.8 kg NH_3, i.e. 13.24 % of the N excretion.
In summer volatilization is higher due to the higher temperature indoors. It was assumed that the temperature in summer is 5 °C higher than in winter and that ammonia volatilization increases by 8 % per °C increase in temperature on a slatted floor and 7 % per °C increase in temperature on a solid floor (De Boer et al., 1994). This implies that 19.45 % of the N excreted is lost by volatilization. These figures are based on an average ration. At an increasing N content in the ration, N excretion increases. If the amount of urine per excretion increases, more or less the same amount remains as a film on the floor and more flows away via the urine ditchtes or slats. This would lead to the same absolute volatilization rates as the standard ration. However if cows are urinating more frequently, this would lead to a similar relative volatilization loss (Smits et al.,

1993). As information on the influence of the ration is not detailed enough to allow for differentiation, the relative figures have been applied in the Dairy Farming Model. The contribution of separate storages to volatilization losses are of the same order of magnitude as from manure stored under a slatted floor (Voorburg & Kroodsma, 1992).
In low-emission stables and storages ammonia volatilization has to be reduced by 4.4 kg per animal in winter, i.e. 50 % of that in the current system (Foundation Green Label, 1993). Several measures can be taken to reduces ammonia losses: an inclined, solid floor with a urine ditch and a flushing system, a slatted floor with a flushing system, an inclined coated floor with at maximum 3 m^2 per cow.

Ammonia volatilization from stable and storage for standard and low-emission constructions under a zero grazing system (% of the N excreted)

Stable and storage type	Period	NH_3 volatilization
Standard	winter	13.24
	summer	19.45
Low-emission	winter	6.62
	summer	9.30

Volatilization in summer is related to the amount of slurry collected inside. It was assumed that on average 50 % of the volatilization originates from the floor and 50 % from other sources (Kroodsma & Huis in 't Veld, 1989, Ketelaars, pers.comm.). This leads to relatively high volatilization rates for the slurry collected around milking of cows that are grazing day-and-night, as the emitting surface is relatively large.
The P/N ratio in slurry is set to 0.15. This was derived from calculations with GRASMOD. N content in the ration is relatively small, so less N per kg P is excreted than according to the standard data.

Prices

Proportion of the herd sold and replaced annually and the price received (National Reference Centre for Agriculture, 1993).

Cattle type	Sale head (head kept)$^{-1}$	Price Dfl head^{-1}
Dairy cow	0.25	1284
Yearling	0.11	822
calf	2.33	235

Each year 25% of the cows is replaced, 30 % of the calves and 90 % of the yearlings is kept.
The annual costs for low-emission constructions for 100 cows were estimated at Dfl 15 507 , i.e. Dfl 155 per cow (Van der Kamp et al., 1993)

Prices of products

Product	Type		Price	Unt
Concentrates (1)	1. low protein		0.33	Dfl kg^{-1} DM
	2. standard		0.37	
	3. moderately low protein		0.40	
	4. protein rich		0.40	
	5. very protein rich		0.48	
	6. low P		0.50	
	artificially dried grass*		0.20	
Fertilizer (1)	N		1.12	Dfl kg^{-1} N
	P		2.14	Dfl kg^{-1} P
	K		0.45	Dfl kg^{-1} K
Slurry application in contract work (1, 2)	grass	deep injection	1.00	Dfl kg^{-1} N
		open-slit injection	1.50	
		surface application	0.90	
		maize/deep injection	1.00	
	fodder beets	incorporation	1.34	
		surface application	0.90	
Milk			0.784	Dfl kg^{-1}

* costs of drying, includes transport (pers. comm. various grass drying factories)

(1) National Reference Centre for Agriculture, 1993

(2) National Reference Centre for Agriculture, 1992

Labour requirements

Labour requirements for the various activities and operations are based on the standards according to the National Reference Centre for Agriculture, division Arable Farming (1992) and to Pelser (1988).

Basic data:

Field size:	**maize and fodder beets 6 ha**
	grassland 2 ha
Distance to farm house:	**0.5 km**
Herd size:	**100 cows**

Milk stable with 16 stands, belongs to 100 cows and can be handled by one person

Contract labour:	**maize and fodder beet cultivation**
	ensiling grass
	slurry application

The total labour requirements are increased by 10 % to account for general labour requirement on farm.

Labour coefficients

	Operation		Summer	Winter	Unit
Grass	grazing		0.8		$h\ ha^{-1}\ cut^{-1}$
	ensiling grass		4.4		$h\ ha^{-1}\ cut^{-1}$
	making hay		10.4		$h\ ha^{-1}\ cut^{-1}$
	harvesting for artificial drying		3.2		$h\ ha^{-1}\ cut^{-1}$
	harvesting for zero grazing		0.65		h per load
	fertilizer application		0.8		$h\ ha^{-1}\ cut^{-1}$
	fixed		3.2		$h\ ha^{-1}\ yr^{-1}$
Maize + fodder beets	fertilizer application		0.5		$h\ ha^{-1}$
Cattle	milking + cleaning machninery		7.4	7.4	$h\ head^{-1}$
	cleaning stable, collecting animals				
		zero grazing	2.3	2.3	$h\ head^{-1}$
		day grazing	1.6	2.3	$h\ head^{-1}$
		day-and-night grazing	0.9	2.3	$h\ head^{-1}$
	feeding:	wilted silage		0.64	$h\ t^{-1}$ DM
		maize silage		0.65	$h\ t^{-1}$ DM
		hay		2.2	$h\ t^{-1}$ DM
		fodder beet		1.52	$h\ t^{-1}$ DM
		beet leaves		1.69	$h\ t^{-1}$ DM
		concentrates		0.19	$h\ t^{-1}$ DM
	taking care of young stock*				
	calf:	zero grazing	1.6	8.3	$h\ head^{-1}$
		day-and-night grazing	2.7	8.3	$h\ head^{-1}$
	yearling:	zero grazing	3.6	3.6	$h\ head^{-1}$
		day-and-night grazing	2.2	3.6	$h\ head^{-1}$

* including feeding

Cost coefficients

Basis situation: large efficiently organized farm with 100 dairy cows

Fixed and variable costs and cost of contract labour

Variable costs crops		(Dfl ha^{-1})
Maize silage no catch crop		560
Ground ear silage no catch crop		670
Maize silage + catch crop		730
Ground ear silage + catch crop		840
Fodder beet		1370
Grassland		243
Storage of silage(Dfl t^{-1})		20
Fixed costs crops (including petrol)		**(Dfl cut^{-1})**
Maize		0
Fodder beet		0
Grazing		51
Ensiling grass		232
Making hay		385
Artificially dried grass		232
Zero grazing, summer feeding		275
Variable costs cattle		**(Dfl $head^{-1}$)**
Dairy cow		277
Yearling		90
Calf		196
Straw	day-and-night grazing	20
	day grazing	25
	zero grazing	30
	calf, yearling	20
Fixed costs cattle		**(Dfl $head^{-1}$)**
Total attributed to cows		1804
Low-emission stable + slurry storage		220
Fixed costs feeding		**(Dfl t^{-1} DM)**
Wilted silage		93
Hay		82
Maize		95
Fodder beets		271
Beet leaves		273
Concentrates		25
Costs contract labour		**(Dfl ha^{-1})**
Silage maize no catch crop		1 800
Ground ear silage no catch crop		1 685
Silage maize + catch crop		2 190
Ground ear silage + catch crop		2 075
Fodder beets		2 410
Grass, reseeding		77
ensiling		260

Costs are split into:

Crops:
- variable costs (seed, standard fertilizer application, conservation of the product, pesticides)
- fixed costs (use of machinery, based on mutual usage, including depreciation, maintenance, insurance and parking shed)
- cost of contract labour

Animals:
- variable costs (care taking, veterinarian, straw etc.)
- fixed costs (milking machines, buildings)

The fixed costs are expressed per ha for the crops and per animal for cattle. Hence they have been converted to the same units a the variable costs.The costs are based on National Reference Centre for Agriculture (1992, 1993)

Appendix C

Results of optimization cycles at a regional scale.

All figures pertain to one average ha in the region. The prefix 'G' in the row names refers to a goal and the prefix 'R' in the column names to a restriction on the goal.

NO_3	nitrate leaching, kg N
NH_3	ammonia volatilization, kg N
NOV	N surplus, kg N
POV	P surplus kg N
MILK	milkproduction, kg milk
INC	labour income, Dfl
RIN	net result, Dfl
LAB	labour, h
LSA	landscape: number of cows outside, head
LSL	landscape: area under wooded banks, proportion

bold : optimal value
italic : binding restriction (has a shadow price)
grey : indicates that the results for the goal are similar to those in the previous iteration

RESULTS ITERATION 1

Goal	Goal restrictions and their values									
	9999	9999	99999	9999	0	99999	-99999	0	999.00	*0.05*
	R-NO3	R-NH3	R-NOV	R-POV	R-MILK	R-INC	R-RIN	R-LAB	R-LSA	R-LSL
G-NO3	**14**	5	129	25	1606	-2999	-4019	33	0	*0.05*
G-NH3	81	**0**	237	35	0	-4241	-4241	0	0	*0.05*
G-NOV	18	21	**24**	3	10642	1119	-671	59	0	0
G-POV	68	48	251	**-8**	10349	-1412	-4069	87	0	0
G-MILK	68	116	379	30	**26360**	5014	1269	123	0	0
G-INC	56	178	395	29	26300	**5249**	1518	122	0	0
G-RIN	103	82	390	8	16428	4692	**2557**	70	2.05	0
G-LABmn	65	0	133	23	*0*	-3944	-3944	**0**	0	*0.05*
G-LABmx	68	104	372	19	17100	-566	-4790	**139**	0	0
G-LSA	88	97	341	14	15891	47	-3132	104	**3.18**	0
G-LSL	59	0	212	35	0	-4213	-4213	0	0	**0.05**

RESULTS ITERATION 2

	Goal restrictions and their values									
Goal	***34***	9999	99999	9999	0	99999	-99999	0	999.00	*0.05*
	R-NO3	R-NH3	R-NOV	R-POV	R-MILK	R-INC	R-RIN	R-LAB	R-LSA	R-LSL
G-NO3	**14**	1	140	30	0	-3070	-3617	18	0	*0.05*
G-NH3	*34*	**0**	144	30	0	-4212	-4513	10	0	0.02
G-NOV	18	21	**24**	3	10642	1119	-671	59	0	0
G-POV	*34*	39	172	**-5**	10052	-1278	-3855	84	0	0
G-MILK	*34*	102	295	46	**25875**	4949	1281	120	0	0
G-INC	*34*	170	341	29	25871	**5199**	1532	120	0	0
G-RIN	*34*	67	232	8	15404	4403	**2399**	66	1.93	0
G-LABmn	*34*	0	171	34	0	-4477	-4549	**2**	0	*0.05*
G-LABmx	*34*	90	287	19	16622	-474	-4580	**135**	0	0
G-LSA	*34*	72	227	22	15182	28	-3013	100	**3.04**	0
G-LSL	14	1	140	30	0	-3070	-3617	18	0	***0.05***

RESULTS ITERATION 3

	Goal restrictions and their values									
Goal	*34*	***30***	99999	9999	0	99999	-99999	0	999	*0.05*
	R-NO3	R-NH3	R-NOV	R-POV	R-MILK	R-INC	R-RIN	R-LAB	R-LSA	R-LSL
G-NO3	**14**	0	140	33	0	-4257	-4786	17	0	*0.05*
G-NH3	*34*	**0**	144	30	0	-4212	-4513	10	0	0.02
G-NOV	18	21	**24**	3	10642	1119	-671	59	0	0
G-POV	*34*	*30*	160	**-4**	9143	73	-1939	66	0.50	*0.05*
G-MILK	*34*	*30*	111	12	**17644**	2956	467	82	0	0
G-INC	*34*	*30*	138	8	16351	**3814**	1636	71	2.04	0
G-RIN	*34*	*30*	154	7	14189	3654	**1851**	59	1.77	0
G-LABmn	*34*	0	171	34	0	-4477	-4549	**2**	0	*0.05*
G-LABmx	*34*	*30*	180	7	11709	-1288	-4538	**107**	0	0
G-LSA	*34*	*30*	143	18	12976	-605	-3143	83	**2.60**	0
G-LSL	14	1	140	30	0	-3070	-3617	18	0	***0.05***

RESULTS ITERATION 4

Goal	Goal restrictions and their values									
	34	*30*	99999	*2.2*	0	99999	-99999	0	999.00	*0.05*
	R-NO3	R-NH3	R-NOV	R-POV	R-MILK	R-INC	R-RIN	R-LAB	R-LSA	R-LSL
G-NO3	**14**	*30*	40	*2.2*	7733	-918	-2889	65	0	*0.05*
G-NH3	*34*	**14**	85	*2.2*	6937	478	-880	45	0.87	*0.05*
G-NOV	19	21	**24**	*2.2*	9397	24	-1850	61	0	0
G-POV	*34*	*30*	160	**-4**	9143	73	-1939	66	0.50	*0.05*
G-MILK	*34*	*30*	120	2.2	**15458**	2156	-157	76	0	0
G-INC	*34*	*30*	170	*2.2*	13869	**3353**	1405	64	1.73	0
G-RIN	*34*	*30*	166	2.2	13583	3299	**1488**	59	1.70	0
G-LABmn	*34*	17	93	*2.2*	7182	326	-742	**35**	0.90	*0.05*
G-LABmx	*34*	*30*	177	*2.2*	10748	-1183	-4378	**105**	0	0
G-LSA	*34*	*30*	145	*2.2*	11247	-603	-2950	77	**2.25**	0
G-LSL	*34*	28	125	*2.2*	5928	-622	-2356	57	1.19	***0.05***

RESULTS ITERATION 5

Goal	Goal restrictions and their values									
	34	*30*	*130*	*2.2*	0	99999	-99999	0	999.00	*0.05*
	R-NO3	R-NH3	R-NOV	R-POV	R-MILK	R-INC	R-RIN	R-LAB	R-LSA	R-LSL
G-NO3	**14**	*30*	38	*2.2*	7703	-1030	-3002	65	0	*0.05*
G-NH3	*34*	**14**	85	*2.2*	6937	478	-880	45	0.87	*0.05*
G-NOV	19	21	**24**	*2.2*	9397	24	-1850	61	0	0
G-POV	*34*	*30*	*130*	**-3.7**	9082	-473	-2493	66	0.68	*0.05*
G-MILK	*34*	*30*	120	*2.2*	**15458**	2156	-157	76	0	0
G-INC	33	*30*	*130*	*2.2*	14951	**3245**	1223	66	1.87	0
G-RIN	25	*30*	*130*	*2.2*	12428	3035	**1342**	56	1.55	0
G-LABmn	*34*	16	92	*2.2*	7182	331	-737	**35**	0.90	*0.05*
G-LABmx	28	*30*	*130*	*2.2*	10441	-1395	-4453	**100**	0	0
G-LSA	*34*	*30*	*130*	*2.2*	11150	-863	-3212	77	**2.23**	0
G-LSL	*34*	19	*130*	*2.2*	7545	765	-785	51	0.96	***0.05***

RESULTS ITERATION 6

Goal	Goal restrictions and their values									
	34	*30*	*130*	*2.2*	*12500*	99999	-99999	0	999.00	*0.05*
	R-NO3	R-NH3	R-NOV	R-POV	R-MILK	R-INC	R-RIN	R-LAB	R-LSA	R-LSL
G-NO3	**14**	*30*	40	*2.2*	7733	-918	-2889	65	0	*0.05*
G-NH3	*34*	**14**	85	*2.2*	6937	478	-880	45	0.87	*0.05*
G-NOV	19	21	**24**	*2.2*	9397	24	-1850	61	0	0
G-POV	*34*	*30*	*130*	**-3.7**	9082	-473	-2493	66	0.68	*0.05*
G-MILK	34	30	127	2.2	***12500***	412	-2159	84	0.06	0
G-INC	26	*30*	*130*	*2.2*	*12500*	**3042**	1334	56	1.56	0
G-RIN	25	*30*	*130*	*2.2*	12428	3035	**1342**	56	1.55	0
G-LABmn	*34*	18	96	*2.2*	7182	305	-762	**35**	0.90	*0.05*
G-LABmx	28	*30*	*130*	*2.2*	10441	-1395	-4453	**100**	0	0
G-LSA	*34*	*30*	*130*	*2.2*	11150	-863	-3212	77	**2.23**	0
G-LSL	*34*	*30*	129	*2.2*	6209	-750	-2351	53	1.24	***0.05***

RESULTS ITERATION 7

Goal	Goal restrictions and their values									
	34	*30*	*130*	*2.2*	*12500*	*0*	-99999	0	999.00	*0.05*
	R-NO3	R-NH3	R-NOV	R-POV	R-MILK	R-INC	R-RIN	R-LAB	R-LSA	R-LSL
G-NO3	**15**	*30*	45	*2.2*	8309	*0*	-1893	62	0.16	*0.05*
G-NH3	*34*	**14**	85	*2.2*	6937	478	-880	45	0.87	*0.05*
G-NOV	19	21	**24**	2.2	9397	*0*	-1875	61	0	0
G-POV	*34*	*30*	*130*	**-3.7**	9705	*0*	-1990	65	0.74	*0.05*
G-MILK	*34*	*30*	127	*2.2*	**12500**	*0*	-2073	68	0.69	0
G-INC	26	*30*	*130*	*2.2*	*12500*	**3042**	1334	56	1.56	0
G-RIN	25	*30*	*130*	*2.2*	12428	3035	**1342**	56	1.55	0
G-LABmn	*34*	18	96	*2.2*	7182	305	-762	**35**	0.90	*0.05*
G-LABmx	25	*30*	*130*	*2.2*	11792	*0*	-2984	**98**	0	0
G-LSA	*34*	*30*	*130*	*2.2*	11480	*0*	-2262	74	**2.18**	0
G-LSL	*34*	16	89	0	7378	*0*	-1466	48	0.90	***0.05***

RESULTS ITERATION 8

	Goal restrictions and their values									
Goal	*34*	*30*	*130*	*2.2*	*12500*	*0*	-99999	0	999.00	*0.050* *0.025*
	R-NO3	R-NH3	R-NOV	R-POV	R-MILK	R-INC	R-RIN	R-LAB	R-LSA	R-LSL
G-NO3	**15**	*30*	45	*2.2*	8309	*0*	-1893	62	0.16	*0.050*
G-NH3	*34*	**14**	85	*2.2*	6937	478	-880	45	0.87	*0.050*
G-NOV	19	21	**25**	*2.2*	9184	*0*	-1825	60	0	*0.025*
G-POV	*34*	*30*	*130*	**-3.7**	9705	*0*	-1990	65	0.74	*0.05*
G-MILK	24	*30*	*130*	*2.2*	***12500***	1225	-1035	74	0.54	*0.025*
G-INC	27	*30*	*130*	*2.2*	*12500*	**2992**	1287	56	1.56	*0.025*
G-RIN	25	*30*	*130*	*2.2*	12162	2961	**1306**	54	1.52	*0.025*
G-LABmn	*34*	16	92	*2.2*	7182	331	-737	**35**	0.90	*0.050*
G-LABmx	25	*30*	*130*	*2.2*	11713	*0*	-2939	**96**	0	*0.025*
G-LSA	*34*	*30*	*130*	*2.2*	11428	*0*	-2253	74	**2.16**	*0.025*
G-LSL	*34*	27	108	0	7414	*0*	-1720	56	0.91	***0.050***

RESULTS ITERATION 9

	Goal restrictions and their values									
Goal	*34*	*30*	*130*	*2.2*	*12500*	*0*	-99999	0	*1.00*	*0.050* *0.025*
	R-NO3	R-NH3	R-NOV	R-POV	R-MILK	R-INC	R-RIN	R-LAB	R-LSA	R-LSL
G-NO3	**15**	*30*	62	*2.2*	8055	*0*	-1691	55	*1.00*	*0.050*
G-NH3	*34*	**14**	83	*2.2*	7305	*0*	-1489	49	*1.00*	*0.050*
G-NOV	20	20	**33**	1.7	8884	513	-1086	52	*1.00*	*0.025*
G-POV	*34*	*30*	*130*	**-3.7**	9686	*0*	-1990	65	*1.00*	*0.025*
G-MILK	*34*	*30*	120	2.2	***12500***	1822	-281	69	*1.00*	0.027
G-INC	27	*30*	*130*	*2.2*	*12500*	**2992**	1287	56	1.56	0.025
G-RIN	25	*30*	*130*	*2.2*	12162	2961	**1306**	54	1.52	0.025
G-LABmn	*34*	*30*	105	*2.2*	8000	646	-471	**37**	*1.00*	0.050
G-LABmx	24	29	*130*	*2.2*	10983	*0*	-2785	**91**	*1.00*	0.025
G-LSA	*34*	*30*	*130*	*2.2*	11428	*0*	-2253	74	**2.16**	0.025
G-LSL	24	*30*	105	*2.2*	8670	*0*	-1517	50	1.22	**0.050**

RESULTS ITERATION 10

	Goal restrictions and their values									
Goal	*34*	*30*	*130*	*2.2*	*12500*	*0*	*0*	0	*1.00*	*0.050* *0.025*
	R-NO3	R-NH3	R-NOV	R-POV	R-MILK	R-INC	R-RIN	R-LAB	R-LSA	R-LSL
G-NO3	**16**	*30*	63	*2.2*	9192	1485	*0*	49	*1.00*	*0.050*
G-NH3	*34*	**15**	86	*2.2*	8000	1439	*0*	47	*1.00*	*0.005*
G-NOV	21	21	**38**	*2.2*	9458	1454	*0*	48	1.18	*0.025*
G-POV	*34*	29	*130*	**-3.3**	11632	1818	*0*	60	*1.00*	*0.025*
G-MILK	*34*	*30*	*130*	*2.2*	***12500***	1868	*0*	61	1.56	*0.050*
G-INC	*27*	*30*	*130*	*2.2*	*12500*	**2992**	1287	56	1.56	*0.025*
G-RIN	25	*30*	*130*	*2.2*	12162	2961	**1306**	54	1.52	*0.025*
G-LABmn	*34*	26	106	*2.2*	8008	1157	*0*	**38**	*1.00*	*0.050*
G-LABmx	27	28	*130*	*2.2*	*12500*	2425	*0*	**79**	1.17	*0.025*
G-LSA	*34*	*30*	*130*	*2.2*	*12500*	1950	*0*	64	**1.84**	*0.025*
G-LSL	31	*30*	95	*2.2*	8390	1365	*0*	45	*1.00*	***0.050***

RESULTS ITERATION 11

	Goal restrictions and their values									
Goal	*34*	*30*	*130*	*2.2*	*12500* *10000*	*0*	*0*	0	*1.00*	*0.050* *0.025*
	R-NO3	R-NH3	R-NOV	R-POV	R-MILK	R-INC	R-RIN	R-LAB	R-LSA	R-LSL
G-NO3	**16**	*30*	68	*2.2*	*10000*	1565	*0*	51	*1.00*	*0.050*
G-NH3	*34*	**18**	84	*2.2*	*10000*	1608	58	51	1.25	*0.050*
G-NOV	19	20	**38**	2	*10000*	1546	*0*	51	1.12	*0.025*
G-POV	*34*	29	*130*	**-3.3**	11632	1818	*0*	60	*1.00*	*0.025*
G-MILK	32	*30*	*130*	*2.2*	**12500**	2084	*0*	68	*1.00*	*0.050*
G-INC	27	*30*	*130*	*2.2*	12500	**2992**	1287	56	1.56	*0.025*
G-RIN	25	*30*	*130*	*2.2*	12162	2961	**1306**	54	1.52	*0.025*
G-LABmn	*34*	24	100	*2.2*	*10000*	1292	0	**42**	1.25	*0.050*
G-LABmx	27	28	*130*	*2.2*	*12500*	2425	*0*	**79**	1.17	*0.025*
G-LSA	*34*	*30*	*130*	*2.2*	*12500*	1950	*0*	64	**1.84**	*0.025*
G-LSL	21	*30*	111	*2.2*	*10000*	2091	345	57	*1.00*	***0.050***

RESULTS ITERATION 12

	Goal restrictions and their values									
	34	*30*	*130*	*0*	*12500*	*0*	*0*	*0*	*1.00*	*0.050*
Goal					*10000*					*0.025*
	R-NO3	R-NH3	R-NOV	R-POV	R-MILK	R-INC	R-RIN	R-LAB	R-LSA	R-LSL
G-NO3	**18**	*30*	84	*0*	*10000*	1683	104	52	*1.00*	0.034
G-NH3	*34*	**19**	101	*0*	*10000*	1625	*0*	53	1.25	0.042
G-NOV	24	21	**57**	*0*	*10000*	1531	*0*	50	1.25	0.025
G-POV	*34*	29	*130*	**-3.3**	11632	1818	*0*	60	*1.00*	0.025
G-MILK	*34*	*30*	*130*	*0*	***12500***	1926	*0*	63	*1.00*	0.050
G-INC	32	29	*130*	*0*	*12500*	**2706**	952	57	1.56	0.025
G-RIN	29	26	*130*	*0*	11369	2594	**999**	52	1.42	0.025
G-LABmn	*34*	*30*	119	*0*	*10000*	1359	*0*	**45**	1.25	0.050
G-LABmx	*30*	28	*130*	*0*	*12500*	2281	*0*	**75**	1.12	0.025
G-LSA	*34*	28	*130*	*0*	*12500*	1930	*0*	63	**1.76**	0.025
G-LSL	32	*30*	129	*0*	*12500*	1908	*0*	63	1.60	**0.050**

Appendix D

Optimization results for the situation at 'De Marke'

Table 1. Optimization results for 'De Marke' at the present farm lay-out and management (simulation): milk production > 12t, NO_3 leaching < 34 kg N, NH_3 volatilization < 30 kg N , P surplus < 0.5 kg. Most figures apply to an average ha farm land. Only rows marked by '*' are expressed per ha of the specific crop.

Goal		Milk production	Labour income	NO_3 leaching	NH_3 volatilization	P surplus	N surplus
Labour income	Dfl	1750	**1770**	1755	1755	1725	1765
Nitrate leaching	kg N	32	32	**32**	32	32	32
Ammonia volatilization	kg N	26	25	25	**25**	27	25
P surplus	kg	0.5	0.5	0.5	0.5	**0.5**	0.5
Milk production	kg	**12010**	12010	12000	12000	12000	12000
N surplus	kg	174	173	175	175	176	**173**
Accum. + denitrification	kg N	117	116	117	117	118	116
Grass fresh (area)	%	44	44	44	44	44	44
N application rate*	kg	280	280	280	280	280	280
Grazing system cows		day grazing+maize	day grazing+maize	day grazing+maize	day grazing+maize	day grazing+maize	day grazing+maize
yearlings		day+night grazing	day+night grazing	day+night grazing	day+night grazing	day+night grazing	day+night grazing
calves		zero grazing-maize	zero grazing-maize	zero grazing-maize	zero grazing-maize	zero grazing-maize	zero grazing-maize
Grass conserved (area)	%	16	16	16	16	16	16
N application rate*	kg	280	280	280	280	280	280
Product (area) hay	%	0	0	0	0	0	0
wilted silage, 3 t	%	16	16	16	16	16	16
wilted silage, 4 t	%	0	0	0	0	0	0
artificially dried grass	%	0	0	0	0	0	0
Maize (area)	%	30	30	30	30	30	30
N application slurry*	kg	133	133	133	133	133	133
Artificial fertilizer*	kg	0	0	0	0	0	0
Slurry placement		broadcast	broadcast	broadcast	broadcast	broadcast	broadcast
Catch crop		+	+	+	+	+	+
Maize silage (area)	%	23	23	23	23	23	23
Ground ear silage (area)	%	7	7	7	7	7	7
Irrigated (area)	%	0	0	0	0	0	0

Table 1 continued

Fodder beet (area)	%	10	10	10	10	10	10
N application slurry*	kg	98	98	98	98	98	98
Artificial fertilizer*	kg	0	0	0	0	0	0
Slurry placement		broadcast	broadcast	broadcast	broadcast	broadcast	broadcast
Slurry	kg N	162	162	162	162	162	162
Grass injection*	kg N	75	75	75	75	75	75
Grass inj. open slits*	kg N	115	115	115	115	115	115
Beet/maize injection*	kg N	122	122	122	122	122	122
Stocking rate	cows	1.41	1.41	1.41	1.41	1.41	1.41
Milk production per cow	kg	8500	8500	8500	8500	8500	8500
Herbage supply level	%	1.00	1.00	1.00	1.00	1.00	1.00
Concentrates purchased	kg	1670	1670	1660	1660	1660	1660
produced on-farm	kg	1200	1200	1200	1200	1200	1200
Concentrates per cow	kg	2035	2035	2028	2028	2028	2028
Stable + slurry storage		low-emission	low-emission	low-emission	low-emission	low-emission	low-emission
Labour input	h	53	53	53	53	53	53
P fertilizer	kg	0.0	0.0	0.0	0.0	0.0	0.1
Income/t milk	Dfl	146	147	146	146	144	147
N input:N output	-	3.3	2.5	3.3	3.3	3.4	3.3
Input							
Deposition	kg N	45	45	45	45	45	45
Concentrates	kg N	98	98	98	97	98	97
Artificial fertilizer	kg N	107	106	107	106	109	106
Total	kg N	250	249	250	248	252	248
Output							
Milk	kg N	64	64	64	64	64	64
Meat	kg N	7	7	7	7	7	7
Roughage	kg N	4	4	4	4	4	4
Total	kg N	75	75	75	75	75	75

Table 2. Optimization results for 'De Marke' under a free farm lay-out and management, but under similar restrictions: milk production > 12t, NO_3 leaching < 34 kg N, NH_3 volatilization < 30 kg N , P surplus < 0.5 kg. Most figures apply to an average ha farm land. Only rows marked by '*' are expressed per ha of the specific crop.

Goal		Milk production	Labour income	NO_3 leaching	NH_3 volatilization	P surplus	N surplus
Labour income	Dfl	3750	**4380**	1650	2145	4210	1120
Nitrate leaching	kg N	34	34	**13**	34	34	24
Ammonia volatilization	kg N	30	30	22	**17**	30	20
P surplus	kg	0.5	0.5	0.5	0.5	**0.0**	0.5
Milk production	kg	**17660**	15350	12000	12000	15177	12000
N surplus	kg	225	269	165	160	269	**94**
Accum. + denitrification	kg N	161	205	129	108	205	50
Grass fresh (area)	%	49	73	54	46	73	43
N application rate*	kg	330(200,300,350)	270(250-400)	216(100,250,300)	190(150,200)	271(250-450)	200
Grazing system cows		zero grazing+maize	day+night grazing	zero grazing-maize day+night grazing	zero grazing+maize	day+night grazing	zero grazing+maize
yearlings		zero grazing-maize	zero grazing-maize	zero grazing-maize	day+night grazing	zero grazing-maize	zero grazing-maize
calves		day+night grazing	zero grazing -maize	zero grazing-maize	day+night grazing	zero grazing-maize	zero grazing-maize
Grass conserved (area)	%	32	27	46	41	27	5
N application rate*	kg	390(200-450)	380(250-450)	180(100,250,300)	315(100-200,450)	387(250-450)	200
Product (area) hay	%	0	0	0	0	0	0
wilted silage, 3 t	%	0	0	19	0	0	0
wilted silage, 4 t	%	32	27	19	41	27	5
artificially dried grass	%	0	0	27	0	0	0
Maize (area)	%	19	0	0	13	0	39
N application slurry*	kg	112			147		115
Artificial fertilizer*	kg	0			0		0
Slurry placement		broadcast			broadcast		row
Catch crop		+			-/+		-/+
Maize silage (area)	%	19			13		39
Ground ear silage (area)	%	0			0		0
Irrigated (area)	%	19			13		25

Table 2 continued

Fodder beet (area)	%	0	0	0	0	0	13
N application slurry*	kg						93
Artificial fertilizer*	kg						0
Slurry placement							row
Slurry	kg N	243	148	162	155	149	169
Grass injection*	kg N	144	118	92	129	119	105
Grass inj. open slits*	kg N	128	29	70	26	30	155
Beet/maize injection*	kg N	112	-	-	147	-	109
Stocking rate	cows	1.86	1.62	1.26	1.26	1.6	1.26
Milk production per cow	kg	9500	9500	9500	9500	9500	9500
Herbage supply level		1.00	1.00	1.00	1.00	1.00	1.00
Concentrates purchased	kg	4068	3640	3752	2116	3508	2728
produced on-farm	kg	0	0	0	0	0	0
Concentrates per cow	kg	2187	2250	2978	1679	2193	2165
Stable + slurry storage		low-emission	low-emission	low-emission	low-emission	low-emission	low-emission
Labour input	h	78	62	57	57	62	50
P fertilizer	kg	0.0	0.0	0.0	4.9	0.0	2.5
Income/t milk	Dfl	212	285	138	179	277	93
N input:N output	-	3.2	4.0	2.6	2.9	4.1	2.0
Input							
Deposition	kg N	45	45	45	45	45	45
Concentrates	kg N	117	99	113	60	98	110
Artificial fertilizer	kg N	166	214	109	139	215	36
Total	kg N	328	358	267	244	358	191
Output							
Milk	kg N	94	81	64	64	80	64
Meat	kg N	9	8	6	6	8	6
Roughage	kg N	0	0	33	13	0	26
Total	kg N	103	89	103	83	88	96

Table 3. Optimization results for 'De Marke' with decreasing the target P surplus, in additon to the other restrictions: milk production > 12t, NO_3 leaching < 34 kg N, NH_3 volatilization < 30 kg N , P surplus < 0.5 kg. Labour income is maximized. Most figures apply to an average ha farm land. Only rows marked by '*' are expressed per ha of the specific crop.

P surplus		0.0 kg	0.5 kg	1.0 kg	2.5 kg	5.0 kg	7.5
Labour income	Dfl	**4210**	**4380**	**4545**	**4941**	**5250**	**5265**
Nitrate leaching	kg N	34	34	34	34	34	34
Ammonia volatilization	kg N	30	30	30	30	30	30
P surplus	kg	0.0	0.5	1.0	2.5	5.0	6.3
Milk production	kg	15177	15350	15530	15921	17110	17460
N surplus	kg	269	269	268	276	277	283
Accum. + denitrification	kg N	205	205	204	212	112	219
Grass fresh (area)	%	73	73	74	76	78	75
N application rate*	kg	271(250-450)	270(250-400)	270(250,300,400)	275(250-350)	280(250-350)	300(250-350)
Grazing system cows		day+night grazing	day+night grazing	day+night grazing	day+night grazing	90% day+night grazing 10% zero grazing-maize	80% day+night grazing 20% zero grazing-maize
yearlings		zero grazing-maize	zero grazing-maize	zero grazing	day+night grazing	day+night grazing	day+night grazing
calves		zero grazing-maize	zero grazing-maize	zero grazing	zero grazing	day+night grazing	day+night grazing
Grass conserved (area)	%	27	27	26	24	22	25
N application rate*	kg	387(250-450)	380(250-450)	390(250-450)	360(250-400)	350(250-450)	315(250-400)
Product (area) hay	%	0	0	0	0	0	16
wilted silage, 3 t	%	0	0	0	0	0	0
wilted silage, 4 t	%	27	27	26	24	22	9
artificially dried grass	%	0	0	0	0	0	0
Maize (area)	%	0	0	0	0	0	0
Fodder beet (area)	%	0	0	0	0	0	0
Slurry	kg N	149	148	146	130	133	137
Grass injection*	kg N	119	118	118	113	111	113
Grass inj. open slits*	kg N	30	29	29	17	22	24

Table 3 continued

Stocking rate	cows	1.6	1.62	1.63	1.68	1.80	1.84
Milk production per cow	kg	9500	9500	9500	9500	9500	9500
Herbage supply level		1.00	1.00	1.00	1.00	1.00	1.00
Concentrates purchased	kg	3508	3640	3765	4090	4970	5330
produced on-farm	kg	0	0	0	0	0	0
Concentrates per cow	kg	2193	2250	2310	2435	2761	2897
Stable + slurry storage		low-emission	low-emission	low-emission	low-emission	low-emission	low-emission
Labour input	h	62	62	63	62	67	75
P fertilizer	kg	0.0	0.0	0.0	0.0	0.0	0.0
Income/t milk	Dfl	277	285	293	310	307	302
N input:N output	-	4.1	4.0	4.0	4.0	3.8	3.8
Input							
Deposition	kg N	45	45	45	45	45	45
Concentrates	kg N	98	99	100	105	113	117
Artificial fertilizer	kg N	215	214	214	219	218	223
Total	kg N	358	358	359	369	376	385
Output							
Milk	kg N	80	81	82	84	91	93
Meat	kg N	8	8	8	8	9	9
Roughage	kg N	0	0	0	0	0	0
Total	kg N	88	89	90	92	100	102

Table 4. Optimization results for 'De Marke' with increasing the proportion of concentrates produced on-fam, in additon to the other restrictions: milk production > 12t, NO_3 leaching < 34 kg N, NH_3 volatilization < 30 kg N , P surplus < 0.5 kg. Labour income is maximized. Most figures apply to an average ha farm land. Only rows marked by '*' are expressed per ha of the specific crop.

Concentrates produced on- farm		25%	50%	75%	90%	95%
Labour income	Dfl	**4285**	**3900**	**3450**	**3024**	**2665**
Nitrate leaching	kg N	34	34	34	34	34
Ammonia volatilization	kg N	30	30	26	26	27
P surplus	kg	0.5	0.5	0.5	0.5	0.5
Milk production	kg	15570	13920	12610	12000	12000
N surplus	kg	264	270	248	231	212
Accum. + denitrification	kg N	201	206	188	171	151
Grass fresh (area)	%	70	63	57	50	45
N application rate*	kg	275(250,400)	305(300-400)	305(250-400)	310(300,350)	325(250-400)
Grazing system cows		90% day+night grazing 10% zero grazing-maize	day+night grazing	day+night grazing	90% day+night grazing 10% zero grazing+maize	60% day+night grazing 40% zero grazing+/-maize
yearlings		zero grazing-maize	zero grazing-maize	zero grazing-maize	zero grazing-maize	zero grazing-maize
calves		zero grazing-maize	zero grazing-maize	zero grazing-maize	zero grazing-maize	zero grazing-maize
Grass conserved (area)	%	30	37	43	44	44
N application rate*	kg	390(300,400,450)	330(300-400)	445(250-400)	350(300-400)	370(250-400)
Product (area) hay	%	0	0	0	0	0
wilted silage, 3 t	%	0	0	0	0	0
wilted silage, 4 t	%	20	19	18	17	17
artificially dried grass	%	10	18	25	27	27
Maize (area)	%	0	0	0	5	11
N application slurry*	kg				0	0
Artificial fertilizer*	kg				55	52
Catch crop					+	+
Maize silage (area)	%				2	2
Ground ear silage (area)	%				3	9
Irrigated (area)	%				5	11

Table 4 continued

Fodder beet (area)	%	0	0	0	0	0
Slurry	kg N	162	151	122	126	149
Grass injection*	kg N	119	118	122	126	134
Grass inj. open slits*	kg N	43	33	0	6	34
Beet/maize injection*	kg N	-	-	-	0	0
Stocking rate	cows	1.64	1.47	1.33	1.26	1.26
Milk production per cow	kg	9500	9500	9500	9500	9500
Herbage supply level		1.00	1.00	1.00	1.00	1.00
Concentrates purchased	kg	3520	2080	975	375	200
produced on-farm	kg	1170	2080	2925	3395	3860
Concentrates per cow	kg	2860	2830	2932	2992	3222
Stable + slurry storage		low-emission	low-emission	88% low emission	76% low emission	65% low emission
Labour input	h	65	59	56	55	57
P fertilizer	kg	0.9	2.2	8.2	10.1	10.9
Income/t milk	Dfl	275	280	274	252	222
N input:N output	-	3.9	4.3	4.4	4.3	4.0
Input						
Deposition	kg N	45	45	45	45	45
Concentrates	kg N	93	79	29	15	10
Artificial fertilizer	kg N	218	227	248	241	228
Total	kg N	356	351	322	301	283
Output						
Milk	kg N	83	74	67	64	64
Meat	kg N	8	7	7	6	6
Roughage	kg N	0	0	0	0	0
Total	kg N	91	81	74	70	70

Table 5. Optimization results for 'De Marke' with increasing the proportion of the area under maize, in additon to the other restrictions: milk production > 12t, NO_3 leaching < 34 kg N, NH_3 volatilization < 30 kg N , P surplus < 0.5 kg. Labour income is maximized. Most figures apply to an average ha farm land. Only rows marked by '*' are expressed per ha of the specific crop.

Maize area		10 %	20 %	30 %	40 %	50 %	60 %
Labour income	Dfl	**4280**	**4125**	**3800**	**3470**	**3100**	**2300**
Nitrate leaching	kg N	34	34	34	34	34	34
Ammonia volatilization	kg N	30	30	29	27	26	29
P surplus	kg	0.5	0.5	0.5	0.5	0.5	0.5
Milk production	kg	15990	16300	15470	14630	13760	13680
N surplus	kg	248	229	204	180	158	140
Accum. + denitrification	kg N	84	165	141	119	98	77
Grass fresh (area)	%	62	53	50	48	45	36
N application rate*	kg	290(250-400)	320(300-400)	320(300-400)	320(300-400)	320(300-400)	350(300-400)
Grazing system cows		day+night grazing day grazing+maize	day grazing+maize	day grazing+maize	day grazing+maize	day grazing+maize	day grazing+maize zero grazing+maize
yearlings		zero grazing-maize	zero grazing-maize	zero grazing-maize	zero grazing-maize	zero grazing-maize	zero grazing-maize
calves		zero grazing-maize	zero grazing-maize	zero grazing-maize	zero grazing-maize	zero grazing-maize	zero grazing-maize
Grass conserved (area)	%	28	27	20	12	5	4
N application rate*	kg	385(250-450)	380(300-400)	380(300-400)	370(300-400)	330(300-400)	350(300-400)
Product (area) hay	%	0	0	0	0	0	0
wilted silage, 3 t	%	0	0	0	0	0	0
wilted silage, 4 t	%	28	27	20	12	5	4
artificially dried grass	%	0	0	0	0	0	0
Maize (area)	%	10	20	30	40	50	60
N application slurry*	kg	95	75	86	95	72	0
Artificial fertilizer*	kg	0	12	5	0	14	58
Slurry placement		row	row	row	row	row	-
Catch crop		+	+	+	+	+	+
Maize silage (area)	%	10	20	30	40	48	53
Ground ear silage (area)	%	0	0	0	0	2	7
Irrigated (area)	%	10	20	30	40	47	22

Table 5 continued

Fodder beet (area)	%	0	0	0	0	0	0
Slurry	kg N	177	197	188	179	169	195
Grass injection*	kg N	114	132	127	118	108	120
Grass inj. open slits*	kg N	54	95	104	117	190	365
Beet/maize injection*	kg N	95	75	86	95	72	0
Stocking rate	cows	1.68	1.72	1.63	1.54	1.45	1.44
Milk production per cow	kg	9500	9500	9500	9500	9500	9500
Herbage supply level		1.00	1.00	1.00	1.00	1.00	0.95
Concentrates purchased	kg	3770	3700	3044	2384	1769	1685
produced on-farm	kg	0	0	0	0	143	460
Concentrates per cow	kg	2244	2151	1867	1548	1319	1490
Stable + slurry storage		low-emission	low-emission	low-emission	low-emission	low-emission	low-emission
Labour input	h	65	66	61	57	52	55
P fertilizer	kg	0.0	0.0	0.0	0.0	0.0	0.0
Income/t milk	Dfl	268	253	246	237	225	168
N input:N output	-	3.6	3.4	3.3	3.1	3.0	2.7
Input							
Deposition	kg N	45	45	45	45	45	45
Concentrates	kg N	102	105	103	102	100	102
Artificial fertilizer	kg N	194	174	146	119	94	74
Total	kg N	341	324	294	266	239	221
Output							
Milk	kg N	85	86	82	78	73	73
Meat	kg N	9	9	8	8	7	7
Roughage	kg N	0	0	0	0	0	1
Total	kg N	94	95	90	86	80	81

Table 6. Optimization results for 'De Marke' with under the various grassland utilization systems, in additon to the other restrictions: milk production > 12t, NO_3 leaching < 34 kg N, NH_3 volatilization < 30 kg N , P surplus < 0.5 kg. Labour income is maximized. Most figures apply to an average ha farm land. Only rows marked by '*' are expressed per ha of the specific crop.

Grassland utilization			zero grazing - maize	zero grazing + maize	day grazing + maize	day + night grazing
Labour income		Dfl	**3870**	**3742**	**4092**	**4288**
Nitrate leaching		kg N	34	34	34	34
Ammonia volatilization		kg N	30	30	29	29
P surplus		kg	0.5	0.5	0.5	0.5
Milk production		kg	17150	17441	15955	15025
N surplus		kg	261	222	237	276
Accum. + denitrification		kg N	197	158	174	212
Grass fresh (area)		%	53	47	55	73
N application rate*		kg	350(250-400)	360(300,350,400)	300(250,300,350)	270(250,300)
Grazing system cows			zero grazing-maize	zero grazing+maize	day grazing+maize	day+night grazing
yearlings			zero grazing-maize	zero grazing-maize	day+night grazing	day+night grazing
calves			zero grazing-maize	zero grazing-maize	day+night grazing	day+night grazing
Grass conserved (area)		%	47	35	28	27
N application rate*		kg	400(250-450)	390(300,350,400)	310(250-400)	360(250-400)
Product (area)	hay	%	8	0	0	0
	wilted silage, 3 t	%	0	0	0	0
	wilted silage, 4 t	%	37	35	28	27
	artificially dried grass	%	2	0	0	0
Maize (area)		%	0	18	17	0
N application slurry*		kg		95	48	
Artificial fertilizer*		kg		0	30 (row)	
Slurry placement				row	row	
Catch crop				+	+	
Maize silage (area)		%		18	17	
Ground ear silage (area)		%		0	0	
Irrigated (area)		%		18	17	

Table 6 continued

Fodder beet (area)	%	0	0	0	0
Slurry	kg N	247	249	177	130
Grass injection*	kg N	152	155	130	115
Grass inj. open slits*	kg N	129	95	75	15
Beet/maize injection*	kg N	-	0	48	-
Stocking rate	cows	1.81	1.84	1.68	1.58
Milk production per cow	kg	9500	9500	9500	9500
Herbage supply level		1.00	1.00	1.00	1.00
Concentrates purchased	kg	3590	3630	3740	3520
produced on-farm	kg	230	0	0	0
Concentrates per cow	kg	2110	1973	2226	2228
Stable + slurry storage		low-emission	low-emission	low-emission	low-emission
Labour input	h	84	78	64	61
P fertilizer	kg	3.7	1.7	0.0	0.0
Income/t milk	Dfl	226	215	256	285
N input:N output	-	3.6	3.2	3.6	4.1
Input					
Deposition	kg N	45	45	45	45
Concentrates	kg N	82	102	104	100
Artificial fertilizer	kg N	234	177	182	218
Total	kg N	361	324	331	363
Output					
Milk	kg N	91	92	85	80
Meat	kg N	9	9	8	8
Roughage	kg N	0	0	0	0
Total	kg N	100	101	93	88

Table 7. Optimization results for 'De Marke' with various milk production levels per cow, in additon to the other restrictions: milk production > 12t, NO_3 leaching < 34 kg N, NH_3 volatilization < 30 kg N , P surplus < 0.5 kg. Labour income is maximized. Most figures apply to an average ha farm land. Only rows marked by '*' are expressed per ha of the specific crop.

Milk production per cow			7500 kg	8500 kg	9500 kg
Labour income		Dfl	**2640**	**3550**	**4380**
Nitrate leaching		kg N	34	34	34
Ammonia volatilization		kg N	30	30	30
P surplus		kg	0.5	0.5	0.5
Milk production		kg	13200	14280	15350
N surplus		kg	267	267	269
Accum. + denitrification		kg N	203	204	205
Grass fresh (area)		%	73	74	73
N application rate*		kg	265(250,400)	265(250,300,400)	270(250-400)
Grazing system	cows		day+night grazing	day+night grazing	day+night grazing
	yearlings		day+night grazing	day+night grazing	zero grazing-maize
	calves		day+night grazing	day+night grazing	zero grazing -maize
Grass conserved (area)		%	27	26	27
N application rate*		kg	390(250,400,450)	390(250-450)	380(250-450)
Product (area)	hay	%	0	0	0
	wilted silage, 3 t	%	0	0	0
	wilted silage, 4 t	%	27	26	27
	artificially dried grass	%	0	0	0
Maize (area)		%	0	0	0
Fodder beet (area)		%	0	0	0
Slurry		kg N	152	149	148
Grass injection*		kg N	120	118	118
Grass inj. open slits*		kg N	32	31	29

Table 7 continued

Stocking rate		cows	1.76	1.68	1.62
Milk production per cow		kg	7500	8500	9500
Herbage supply level			1.00	1.00	1.00
Concentrates	purchased	kg	3072	3345	3640
	produced on-farm	kg	0	0	0
Concentrates per cow		kg	1745	1991	2250
Stable + slurry storage			low-emission	low-emission	low-emission
Labour input		h	66	64	62
P fertilizer		kg	0.0	0.0	0.0
Income/t milk		Dfl	200	249	285
N input:N output		-	4.4	4.2	4.0
Input					
Deposition		kg N	45	45	45
Concentrates		kg N	89	94	99
Artificial fertilizer		kg N	212	212	214
Total		kg N	346	351	358
Output					
Milk		kg N	70	76	81
Meat		kg N	9	8	8
Roughage		kg N	0	0	0
Total		kg N	79	84	89

Table 8. Optimization results for 'De Marke' with various milk quota per ha, in additon to the other restrictions: milk production > 12t, NO_3 leaching < 34 kg N, NH_3 volatilization < 30 kg N , P surplus < 0.5 kg. Labour income is maximized. Most figures apply to an average ha farm land. Only rows marked by '*' are expressed per ha of the specific crop.

Milk quota		13 t ha^{-1}	12 t ha^{-1}	14 t ha^{-1}	15.3 t ha^{-1}
Labour income	Dfl	**3800**	**3460**	**4082**	**4380**
Nitrate leaching	kg N	34	34	34	34
Ammonia volatilization	kg N	30	29	28	30
P surplus	kg	0.5	0.5	0.5	0,5
Milk production	kg	13000	12000	14000	15350
N surplus	kg	263	251	267	269
Accum. + denitrification	kg N	199	188	204	205
Grass fresh (area)	%	67	64	70	73
N application rate*	kg	235(200,250)	225(200,250)	255(250,450)	270(250-400)
Grazing system cows		day+night grazing	day+night grazing	day+night grazing	day+night grazing
yearlings		day+night grazing	day+night grazing	day+night grazing	
calves		day+night grazing	day+night grazing	zero grazing	zero grazing-maize
Grass conserved (area)	%	33	36	30	zero grazing -maize
N application rate*	kg	400(200,250,450)	405(200,250,450)	400(250,400,450)	27
Product (area) hay	%	0	7	0	380(250-450)
wilted silage, 3 t	%	0	0	0	0
wilted silage, 4 t	%	30	27	30	0
artificially dried grass	%	0	2	0	27
Maize (area)	%	0	0	0	0
Fodder beet (area)	%	0	0	0	0
Slurry	kg N	139	125	142	148
Grass injection*	kg N	122	125	120	118
Grass inj. open slits*	kg N	17	0	22	29

Table 8 continued

Stocking rate	cows	1.37	1.27	1.47	1.62
Milk production per cow	kg	9500	9500	9500	9500
Herbage supply level		1.00	1.00	1.00	1.00
Concentrates purchased	kg	2158	1570	2740	3640
produced on-farm	kg	0	225	0	0
Concentrates per cow	kg	1575	1413	1864	2250
Stable + slurry storage		75% low-emission	42% low-emission	low-emission	low-emission
Labour input	h	56	55	58	62
P fertilizer	kg	0.3	2.9	0.0	0.0
Income/t milk	Dfl	292	288	292	285
N input:N output	-	4.4	4.6	4.3	4.0
Input					
Deposition	kg N	45	45	45	45
Concentrates	kg N	85	62	91	99
Artificial fertilizer	kg N	208	214	212	214
Total	kg N	338	321	348	358
Output					
Milk	kg N	69	64	74	81
Meat	kg N	7	6	7	8
Roughage	kg N	0	0	0	0
Total	kg N	76	70	81	89

Table 9. Optimization results for 'De Marke' with a high mineralization rate and higher leaching losses from grassland, the restrictions remain the same: milk production > 12t, NO_3 leaching < 34 kg N, NH_3 volatilization < 30 kg N , P surplus < 0.5 kg. Labour income is maximized. Most figures apply to an average ha farm land. Only rows marked by '*' are expressed per ha of the specific crop.

Goal		Labour income	Milk production	NO_3 leaching	NH_3 volatilization	P surplus	N surplus
Labour income	Dfl	**4665**	3830	1120	1940	4320	1270
Nitrate leaching	kg N	34	34	**16**	34	34	20
Ammonia volatilization	kg N	30	30	27	**19**	30	21
P surplus	kg	0.5	0.5	0.5	0.5	**0.0**	0.5
Milk production	kg	15590	**17400**	12000	12000	15110	12000
N surplus	kg	187	159	82	100	215	**51**
Accum. + denitrification	kg N	120	95	39	47	151	9
Grass fresh (area)	%	74	51	54	46	71	44
N application rate*	kg	105	60	0	45	130	0
Grazing system cows		93% day+night grazing 7% zero grazing-maize	zero grazing+maize	zero grazing-maize	zero grazing+maize	day+night grazing	zero grazing+maize
yearlings		day+night grazing	day+night grazing	zero grazing-maize	day+night grazing	day+night grazing	zero grazing-maize
calves		zero grazing-maize	day+night grazing	zero grazing-maize	day+night grazing	zero grazing	zero grazing-maize
Grass conserved (area)	%	26	30	54	32	29	28
N application rate*	kg	240	260	45	250	125	0
Product (area) hay	%	0	0	0	0	0	0
wilted silage, 3 t	%	0	0	23	0	0	0
wilted silage, 4 t	%	26	28	0	23	29	13
artificially dried grass	%	0	2	31	9	0	15
Maize (area)	%	0	18	0	21	0	21
N application slurry*	kg		112		120		115
Artificial fertilizer*			broadcast		broadcast		row
Slurry placement	kg		-		0		0
Catch crop			+		+		+
Maize silage (area)	%		18		21		21
Ground ear silage (area)	%		0		0		0
Irrigated (area)	%		18		0		17

Table 9 continued

Fodder beet (area)	%	0	0	0	0	0	0
Stocking rate	cows	1.64	1.83	1.26	1.26	1.59	1.26
Milk production per cow	kg	9500	9500	9500	9500	9500	9500
Herbage supply level	%	100	100	100	100	100	100
Concentrates purchased	kg	3785	4155	3942	1068	3487	3086
produced on-farm	kg	0	180	0	1626	0	0
Concentrates per cow	kg	2310	2270	3130	2140	2140	2450
Stable + slurry storage		low-emission	low-emission	low-emission	low-emission	low-emission	low-emission
Labour input	h	63	76	60	56	61	54
P fertilizer	kg	0.3	0.9	0.0	8.5	0.0	2.4
Income/t milk	Dfl	299	220	93	162	286	106
N input:N output	-	3.1	2.6	1.7	2.2	3.4	1.5
Input							
Deposition	kg N	45	45	45	45	45	45
Concentrates	kg N	92	103	141	36	98	111
Artificial fertilizer	kg N	141	112	24	100	159	0
Total	kg N	278	260	210	181	302	156
Output							
Milk	kg N	83	92	64	64	80	64
Meat	kg N	8	9	6	6	8	6
Roughage	kg N	0	0	57	12	0	35
Total	kg N	91	101	127	82	88	105

Curriculum vitae

Gertruda Wilhelmina Judoca van de Ven werd geboren op 31 december 1958 te Veldhoven. In 1977 behaalde zij het gymnasium-B diploma aan het van Jacob van Maerlantlyceum te Eindhoven. Aansluitend studeerde zij Landbouw-plantenteelt aan de toenmalige Landbouwhogeschool te Wageningen. Zij heeft ruim vier en halve maand stage gelopen op Invermay, een landbouwkundig onderzoeksinstituut in Nieuw Zeeland, en 6 weken op een boerderij met melkvee en schapen op Texel. Het doctoraalexamen werd behaald in 1984 en bestond uit de vakken De leer van het Grasland, Theoretische Teeltkunde en Algemene Agrarische Economie. Op 1 januari 1985 trad zij in dienst van het Instituut voor Agrobiologisch en Bodemvruchtbaarheidsonderzoek (AB-DLO, voormalig CABO). Daar werkte zij tot midden 1987 aan een project over regionale planning van de landbouw in het noordwestelijk kustgebied van Egypte. Daarna heeft zij gedurende een jaar gewerkt aan kwantificering van de kaliumkringloop op grasland. Vervolgens is het project 'Optimalisering van ruwvoederproduktie en gebruik van dierlijke mest in de melkveehouderij op zandgrond' gestart, wat uiteindelijk in dit proefschrift resulteerde. Tussendoor heeft zij gedurende ca. 6 maanden in opdracht van OSL en de FAO gewerkt aan een rapport over duurzame gewasproduktie en -bescherming in zowel ontwikkelde als ontwikkelingslanden. Tevens was zij projectleider van een project over kwantificering van fosforstromen in grasland. Sinds eind 1994 werkt zij samen met economen en sociologen aan verklaring van input-output relaties op melkveebedrijven op zandgrond in Nederland. Daarbij wordt o.a. gebruikt gemaakt van het in dit proefschrift beschreven Melkveehouderijmodel. De komende tijd zal zij zich bezig houden met verdere uitbreiding en toepassing van het Melkveehouderijmodel voor regionale planning.