Comparing specialised and mixed farming systems in the clay areas of the Netherlands under future policy scenarios: an optimisation approach

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Jules Bos

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Abstract

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Increasing attention for the sustainability concept also caused renewed interest in mixed farming systems in the Netherlands, which supposedly have some advantages over specialised farming systems. These advantages are not unambiguous and may also be realised in specialised farming systems. A systematic quantification of differences in environmental and economic performance between specialised and mixed farming systems was therefore considered useful. The multiple goal linear programming model developed in this study optimises the configuration of regionally specialised or mixed farming systems, subject to a set of constraints, to one of a set of defined objectives, selecting from a large set of agricultural activities. A second focal point of this thesis is agricultural policy analysis. With regard to these policies, numerous 'what if' questions can be posed. Such questions addressed in this thesis consider the optimal configuration of farming systems under Dutch manure policy regulations, the efficacy of these regulations in reducing emissions and the impact of reforms of the European Union's Common Agricultural Policy (CAP) on optimal configuration of farming systems.

Model results suggest that economic performance of mixed farming systems is better than that of specialised farming systems. Differences in economic performance originate from agronomic-technical, organisational and institutional differences. Significant differences in environmental performance are absent.

Dutch manure policy regulations still allow agricultural practices that are associated with relatively high leaching losses. It is proposed to implement additional, means-oriented policy instruments, specifically targeted to reducing leaching loss and incorporating financial incentives.

Moderate CAP reforms as anticipated in Agenda 2000 are not likely to induce drastic changes in land use in the Netherlands other than resulting from autonomous developments. In contrast, a drastic reform - full liberalisation - is likely associated with considerable changes in agricultural land use. Farms will roughly be divided in two categories: large-scale, highly specialised farms and farms combining food production with contributions to other societal goals.

Keywords: interdisciplinary analysis, mixed farming, linear programming, agricultural policy, environmental policy, farming systems research, nitrogen, nutrient balance, leaching, ammonia, volatilisation, CAP.

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CHAPTER 1

General introduction

1.1 The search for 'sustainable' farming systems

A popular point of view at Wageningen University, and in the Netherlands, is to approach sustainability as a subjective concept (e.g. this thesis; Cornelissen *et al.*, 2001; Anonymous, 1995; de Wit *et al.*, 1995), involving concerns about context-dependent ecological, economic and societal issues. With reference to agricultural production systems, these issues range from meeting a need for sufficient, safe and inexpensive food products to achieving agricultural production practices without undesirable side effects, such as decline of rural communities, emissions of pesticides and nutrients, decline of biodiversity and landscape values, high water and energy consumption and the neglect of animal well-being. Such a fuzzy approach hampers the assessment of sustainability of agricultural production systems due to lack of explicitly defined objectives: 'sustainability' has become a buzzword.

At the other end of the spectrum are, for example, Goodland & Daly (1996) and Hueting & Reijnders (1998), who approach (environmental) sustainability as an objective, universal and non-negotiable concept. In their view, agricultural production systems are simply *not* sustainable when they deplete the environmental capital, defined as the possible future functions of the environment and natural resources. An example of environmental capital depletion by agriculture is the consumption of fossil, non-renewable energy, without compensating for the reduction in the stock of fossil energy sources by a new, renewable source which can provide an equivalent amount of energy. Another example is the on-going accumulation of phosphorus in many Dutch agricultural soils, depleting their storage capacity.

Whichever view on 'sustainability' is adhered to, there is agreement on the unsustainability of some features of current Dutch agriculture. The associated features cannot be addressed one-by-one, but call for a reorientation of entire farming systems to what is generally termed 'a more sustainable agriculture' (ten Berge *et al.*, 2000). Given the complexity of the sustainability issues, the contribution of this thesis to the ongoing debate can only be modest: it intends to improve our understanding of Dutch farming systems by unravelling some of its governing mechanisms. Such a better understanding could support decision making processes aimed at reducing unsustainability of Dutch agriculture.

Part of the agricultural sustainability issues results from the adoption of narrow crop rotations, the over-concentration of landless animal production systems in some regions, the use of high levels of external inputs such as mineral fertilisers, pesticides and concentrates, and the associated low input use efficiencies per unit of product and per ha. One way to 'a more sustainable agriculture' could be re-introduction of mixed farming systems in which products, services and resources are exchanged among production branches. According to Lantinga & Rabbinge (1996), mixed farming systems have advantages over specialised farming systems:

- higher nutrient use efficiency and reduction of use of external inputs through (i) use of home-grown concentrates (less purchased concentrates), (ii) more efficient application of animal manure, and (iii) widening the crop rotation (less pesticide use and higher yields due to less problems with soil-borne pests and diseases);
- better utilisation of available labour and spreading of income risks.

In view of this, one of the consequences of the sustainability notion in the Netherlands was a renewed interest in mixed farming systems, which became manifest in increased research efforts (this thesis; Wolfert, 2002; van Keulen *et al*., 1998; Oomen *et al*., 1998; Lantinga & van Laar, 1997; van Niejenhuis & Renkema, 1996; Lantinga & Rabbinge, 1996; de Koeijer *et al*., 1995). Much of this research was centred around empirical farming systems research conducted at one of the experimental farms of Wageningen University, the A.P. Minderhoudhoeve (Swifterbant, Flevoland province, Netherlands). In 1995, this farm was split into two prototype mixed farms: an integrated mixed farm (135 ha) and an ecological mixed farm (90 ha). Each of the farms was characterised by its own objectives and constraints (see Lantinga & van Laar, 1997), to which management was adapted. A common feature was the integration of animal husbandry and arable crop production on the farm. The aim of the research conducted at both farms was to develop 'sustainable' mixed farming systems through monitoring, analysis and adaptation.

A systematic procedure for development of farming systems, starting from well-defined objectives, was formalised and coined 'prototyping' by Vereijken (1994; 1997). Prototyping involves application-oriented design and testing of farming systems in collaboration with commercial farmers or at experimental farms, according to a methodical approach. Four phases can be distinguished (ten Berge *et al*., 2000; Rossing *et al*., 1997a): diagnosis, design, testing and improvement and dissemination. The diagnostic phase comprises identification and analysis of problems in current systems, and explicit assessment of stakeholders' goals. This phase is pivotal for subsequent phases as it involves the subjective identification of stakeholders (e.g. national government, regional or local authorities, farmers, environmental and other non-governmental organisations, residents, consumers, etc.) adhering to mutually conflicting goals. In the design phase, stakeholders and researchers set out to design new production systems that better meet the objectives, eventuating in a number of promising theoretical prototypes. These are subsequently implemented, tested (operational feasibility, economic and environmental performance) and improved empirically in the test phase. In the final phase, the resulting prototypes are promoted among farmers, who will adapt and/or refine them to meet their specific local conditions.

Farm modellers claim that farm modelling can provide an effective complement to empirical work in the above prototyping sequence *inter alia* because (ten Berge *et al.*, 2000; Rossing *et al.*, 1997a): (i) only few farm prototypes can be tested experimentally, while a much larger number and a larger spectrum can be examined numerically and (ii) models allow better specification of the trade-offs between conflicting goals. Hence, traditionally, model analyses have played a role in each of the four phases en route towards ‘more sustainable farming systems’ (e.g. van Latesteijn, 1999; Rabbinge & van Latesteijn, 1992; van de Ven, 1996; Rossing *et al.*, 1997a; Habekotté & Schans, 1996), with varying degrees of success.

1.2 Objectives of the study

In its early stages, the modelling work presented in this thesis intended to contribute to the exploration and design of mixed farming systems in general and the ‘integrated’ prototype mixed farming system at the A.P. Minderhoudhoeve in particular, in a way as outlined and motivated above. However, development of a model that would be able to cover crop and animal management as practised at the A.P. Minderhoudhoeve was constrained by limited availability of data and time. Both constraints relate to e.g. the many crop species cultivated at the farm, the intricate design of the adopted crop rotation and the novelty of applied management (e.g. Lantinga & van Bruchem, 1998; Lantinga & van Laar, 1997). Consequently, the link between the empirical part (the A.P. Minderhoudhoeve) and the modelling part (this thesis) gradually became weaker, and hence the prototyping-supporting function of the latter.

Alternatively, emphasis was shifted towards analysing differences in environmental and economic performance between specialised and mixed farming systems and towards policy analysis. The objective of comparing specialised and mixed farming systems was to contribute to the discussion on the desirability of re-introducing mixed farming systems in the Netherlands. The shift towards policy analysis was inspired by major changes in the policy environment awaiting Dutch farming systems in the near-future, notably the introduction of MINAS and the manure contract system (e.g. Henkens & van Keulen, 2001) and reforms of the evermore heavily debated (e.g. Anonymous, 2002; van der Bijl, 1999) EU Common Agricultural Policy (CAP). In reference to these policies, numerous 'what if' questions can be posed. Such questions addressed in this thesis consider the optimal configuration of specialised and mixed farming systems under Dutch manure policy regulations, the efficacy of manure policy regulations in sufficiently reducing emissions and the impact of moderate and drastic CAP reforms on optimal configuration of specialised and mixed farming systems.

Part of the advantages attributed to mixed farming systems by Lantinga & Rabbinge (1996) may also be realised in specialised farming systems. Hence, analysing differences in environmental and economic performance between specialised and mixed farming systems requires a systematic approach. Modelling enables a transparent and consistent quantification of these differences and is taken as starting-point in this study. Each model is a simplification of reality. In this study, emphasis is on agronomic-technical differences, whilst economic differences are only partially taken into account (see Section 1.4). The main objectives of the research described in this thesis are to:

(1) systematically quantify agronomic-technical differences between specialised and mixed farming systems;
(2) systematically quantify differences in environmental and economic performance between specialised and mixed farming systems in current and conceivable future policy environments, as resulting from the agronomic-technical differences quantified under (1);
(3) test the efficacy of anticipated policies in attaining the pursued policy objectives;
(4) when required, formulate alternative policy scenarios that better effectuate the pursued objectives.

1.3 Modelling framework

The modelling technique applied is multiple goal linear programming (MGLP; de Wit *et al.*, 1988). This technique has proven to be useful to explore possibilities for interweaving conflicting objectives and to quantify trade-offs between them (e.g. ten Berge *et al.*, 2000; van de Ven, 1996.) It is based on a linear programming approach that optimises the configuration of farming systems to one of a set of objective variables (Figure 1.1). In the approach, farming systems are viewed as being composed of so-called activities. Activities comprise sets of coherent operations, each set corresponding to a particular way of producing a crop or animal product. Thousands of activities may be defined, including cropping activities, animal husbandry activities and any other activities related to agriculture, each of which is eligible for adoption in farming systems. Each activity is characterised by so-called input-output coefficients. Input-output coefficients are strongly linked to the goals pursued with the agricultural production system (e.g. food production, income generation, maintenance of soil fertility, minimising environmental impact, etc.) and describe inputs (e.g. nutrients, pesticides, labour and machines) and desired and undesired outputs (e.g. products, nitrate leaching). In quantifying input-output coefficients of each activity, a so-called target-oriented approach (van Ittersum & Rabbinge, 1997) is used: inputs are quantified to realise *a priori* set yield targets. Quantification is

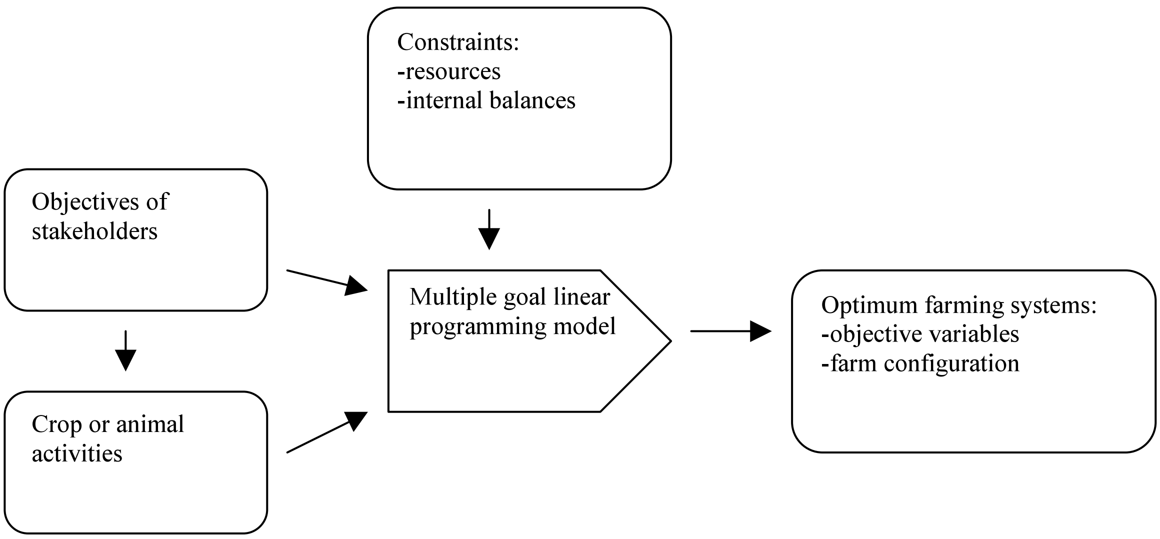

Figure 1.1. Schematic representation of multiple goal linear programming

based on knowledge of the physiological and ecological processes involved in crop growth rather than on statistics or extrapolations as in econometric approaches. Each activity not only contributes to the selected objective variable, but also lays a claim to limited resources, such as land, animal feed or maximum permissible emission. The sum of activities' claims is then subject to a constraint, dictated either by an *a priori* set value or by the production of the resource as determined by other activities.
The MGLP model integrates all activities with underlying input-output tables in one optimisation matrix. The model is mathematically formulated as a mixed integer LP problem:

$$\text{Max or Min } \{w = c'x\}$$

$$\mathbf{A}x \leq b$$

$$x \geq 0$$

$$x_j \text{ integer}, j \in I \subset \{1,2,3,\ldots,n\}$$

Objective function w is a linear function of the n activities (x) and their respective contributions c to the objective variable. **A** is an $m \times n$ matrix with input-output coefficients. The m rows in the matrix are linear mathematical equations representing the objective function and constraints. All equations must satisfy a right hand side vector b, which includes the system boundaries and the constraints set to the problem. The n columns are the activities in these equations. I is the index set of all integer variables. Values of all activities are determined by numerical optimisation, i.e. by solving the matrix for the objective function. The solution is a set of values attached to selected activities (in Operational Research jargon: decision variables), describing the farming system, optimal for the considered objective variable.

1.4 Delineation of the study

The purpose of a study determines the agricultural activities that should be included in the analysis. If the purpose is to explore options for future agricultural production systems (e.g. Rabbinge & van Latesteijn, 1992, Rossing *et al.*, 1997b), it is important to 'look ahead', i.e. to include 'innovative' activities, being developed in the R&D pipeline, in addition to currently practised activities. If the purpose is to evaluate near-future policies in attaining the pursued policy objectives and analyse the 'behaviour' of farming systems under these policies - as is the case in this study -, emphasis should be on currently practised activities, as inclusion of 'innovative' activities might hamper proper evaluation of policies. This implies that the time horizon of this study is relatively short.

Defined agricultural activities refer to arable cropping, dairy farming and landless pig production. Arable cropping and dairy farming cover the major agricultural sectors in the Netherlands in terms of land use. Pig production is included as a representative of landless animal production sectors. Important agricultural sectors that are not explicitly considered include poultry production, sow husbandry, outdoor horticulture, flower bulb production and mutton production. Activities complying with the standards for organic farming are not considered.

This study considers the organisation and configuration of farming systems in an imaginary region, 'located' in the Flevoland province. Thus, agronomic input-output coefficients were derived as much as possible from field experiments and literature referring to the physical environment of Flevoland. 'Building blocks' of farming systems in the region are (1) dairy farming, (2) arable cropping and (3) landless pig production. Two types of organisation of farming systems are distinguished: specialised farming and mixed farming. Specialised farming is characterised by three key features, distinguishing it from mixed farming:

(1) each of the three building blocks of a specialised farming system functions as an independent economic unit;
(2) there is no exchange of land, labour and capital between these economic units;
(3) products and by-products can be exchanged, but are priced.

Mixed farming is defined as the 'opposite', i.e. by merging the three economic units to form one new economic unit, by allowing the exchange of land, labour and capital and by removing price tags attached to exchanged (by-)products.

Since the introduction of labour-saving technologies with high fixed costs, economies of scale have strongly determined and still determine development paths of specialised and mixed farming systems in the Netherlands, and largely explain the rapid specialisation of Dutch agriculture since the 1950s. Economies of scale are however not considered in this study, mainly due to time constraints. They are excluded from the analysis by expressing *all* input-output coefficients on a ha basis, including fixed costs (see Chapter 4). This implies that farm-specific fixed costs, i.e. those determined by e.g. farm size, size of the animal herd and purchased machinery, are only partially taken into account. Consequently, presented economic model results can not be interpreted indiscriminately at farm level. However, the results under the various scenarios are mutually comparable, as they are calculated on the basis of similar starting-points.

Mixed farming systems can exist at different organisational scales. Mixed farming systems *at farm scale*, i.e. all farms producing both animal *and* arable products, have disadvantages: they require farmers to be skilled in a wide range of activities and limit opportunities to profit from economies of scale. In mixed farming systems *at regional scale*, comprising at least two co-operating specialised farms, each producing crops *or* animal products, these disadvantages are absent. The extent to which specialised farms co-operate may vary, ranging from the exchange of manure for feed only, to merging two or more specialised farms into one new mixed farm, adapting the farm plan to the newly created situation. In any case, mixed farming systems at regional scale require participating farmers to sacrifice part of their independence and accept the complexity of arrangements needed for their organisation. In general, loss of independence and complexity of arrangements increase with the intensity of co-operation between farms. Hence, both mixed farming systems at farm scale and at regional scale have trade-offs. The optimum situation in farm-economic terms is very much situation-specific and determined by the balance between production costs, transport costs and intra-farm, inter-farm and market-related co-ordination costs (van Niejenhuis & Renkema, 1996; Schmitt, 1985). This balance under various farming structures (size of farms, organisation of farms) is not considered. Consequently, this study can not and does not provide an overall-assessment of the (un)attractiveness of mixed farming systems compared to specialised farming systems. However, the study does provide a *normative* assessment of (1) agronomic-technical differences and (2) environmental and economic differences, as resulting from the agronomic-technical differences in current and future policy environments.

1.5 Synopsis

Chapter 2 presents the environmental and economic effects of merging a specialised arable farm and a specialised dairy farm to one mixed farm. This chapter was written before developing the modelling framework and is based on relatively simple spreadsheet calculations. Its main purpose was to identify the major issues that play a role when analysing specialised and mixed farming systems. Hence, it also served to guide the conceptual design of the modelling framework developed in the subsequent stage of the research project.

Agricultural activities considered in this study and eligible for adoption in farming systems are defined in Chapter 3. In addition, part of the input-output coefficients of each activity are quantified, notably agronomic coefficients. Other input-output coefficients are quantified in Chapter 4, along with a description of the optimisation matrix. Chapters 5 through 7 report on analyses with the MGLP model. Chapter 5 addresses the impact of Dutch manure policy as anticipated for the year 2003 on environmental and economic performance of specialised and mixed farming systems. Simultaneously, the efficacy of the manure policy in reducing excess nutrient emissions is evaluated. Based on the results reported in Chapter 5, optional adjustments to the design of Dutch manure policy are discussed and their impacts on environmental and economic performance of farming systems quantified (Chapter 6). Chapter 7 reports on the impact of two CAP scenarios on specialised and mixed farming systems. The first scenario is a scenario foreseen for the near-future, known as Agenda 2000. The second scenario is derived in response to existing criticism on the CAP and implies elimination of all product-tied support. In the final Chapter 8 results are synthesised and put in perspective.

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CHAPTER 2

Mixing specialised farming systems in Flevoland (The Netherlands): agronomic, environmental and socio-economic effects

2.1 Introduction

A farm system can be defined as a decision-making unit comprising the farm household and/or cropping and livestock systems, that transforms land, capital and labour into useful products that can be consumed or sold (Fresco & Westphal, 1988). The term farming system is used to refer to a class of similarly structured farm systems. Based on Steinfeld & Mäki-Hokkonen (1995), a mixed farming system is defined as a farming system comprising at least one cropping system and one livestock system, in which more than 10 percent of the dry matter fed to animals is farm-produced or more than 10 percent of the total value of production comes from non-livestock farming activities.

Farming systems are subject to two opposite forces: differentiating forces and integrating forces (Schmitt, 1985; van Niejenhuis & Renkema, 1996). Differentiating forces lead to specialisation, leaving few or only one cropping or livestock system(s) at the farm. Differentiating forces represent the requirements that crops and animals place on their physical environment, local price ratios between products and production factors, the skills and preferences of the farmer, and cost savings related to large-scale production. Integrating forces lead to farming systems, in which several cropping and/or livestock systems are combined. Integrating forces are the need to maintain soil fertility, balance labour requirements of crops and/or animals with available labour, balance feed rations of animals, spread financial and plant/animal health risks, and costs of trading and transporting intermediate products. The impact of both opposite forces has led to mixed farms in the past, but since the 1950s, through the application of labour-saving technologies with high fixed costs (mechanisation, housing systems), differentiating forces have become dominant, leading to rapid specialisation in Dutch agriculture. However, in the past decade a new integrating force has become prominent (van Niejenhuis & Renkema, 1996): the need to enhance sustainability. A way to achieve this could be re-introduction of mixed farming systems, which compared with specialised farming systems, may result in (Lantinga & Rabbinge, 1996):

- higher nutrient use efficiency (i.e. the proportion of imported nutrients exported from the farming system in farm products);
- reduction in the use of external inputs (fertilisers, pesticides, concentrates);
- better utilisation of available labour.

Most important mechanisms underlying these expected benefits are use of on-farm produced concentrates, more efficient use of animal manure and wider crop rotations, including grass and fodder crops.
Mixed farming systems at farm level, i.e. all farms producing both animal and arable products, have disadvantages: they are more difficult to manage, require higher investments (Aarts, 1992) and provide fewer opportunities to take advantage of large-scale production. However, mixed farming systems can exist at different organisational levels. At regional level, a mixed farming system comprises at least two specialised farms, each producing crop or animal products in which decisions are made, taking into account goals and constraints of both farms. In mixed farming systems at regional level, the economic benefits of specialisation at farm level and environmental benefits of integrating cropping and livestock systems at regional level are combined (van Niejenhuis & Renkema, 1996). Therefore, they deserve further attention. The aim of this paper is to compare agronomic, environmental and socio-economic characteristics of two specialised farming systems with those of one mixed farming system at regional level.
In this study, the two specialised farming systems are a specialised arable farm and a specialised dairy farm. The extent to which these specialised farms increase their integration may vary, ranging from the exchange of labour and machinery only, to merging both specialised farms into one new mixed farm, adapting the farm plan (crop areas, animal numbers, buildings and machinery) to the newly created situation. De Koeijer *et al.* (1995), in a study at farm level, quantified effects of merging a specialised arable and a specialised dairy farm. Optimising the farm plan of their mixed farm, resulted in a shift in land use towards more profitable crops at the expense of feed crops. In this study, at regional level, we do not allow changes of the farm plan of the mixed system, to guarantee that only effects of mixing specialised farming systems are quantified and not effects of, for example, shifts in land use. Thus, in this paper the mixed farming system is defined by the specialised arable and the specialised dairy farm, intensively co-operating, exchanging land, labour and machinery. Our key question is: What are the agronomic, environmental and socio-economic effects of re-organising a specialised arable farm and a specialised dairy farm towards more integration, fixing crop areas and animal numbers, and using the same quantities of land and capital? Formulated in another way, we try to quantify the extent to which the utilisation of already present human (labour), capital (machines) and natural (nutrients, soil fertility)

resources can be improved through mixing specialised farming systems, without changing crop areas and animal numbers.

2.2 Methodology

General

Nutrient input/output ratios and scope for reducing pesticide use without yield losses are selected as indicators for natural resource use efficiency. Farm-labour utilisation serves as an indicator for utilisation of human resources. Since effects of changes in utilisation of labour, capital and natural resources are integrated in the generated labour income, this is selected as an overall indicator for economic efficiency. Values of these indicators are quantified for all three farming systems.

In this study many data are fixed (crop areas, machinery, animal numbers). Therefore, relatively straightforward spreadsheet calculations sufficed to answer the questions raised. These are based on a normative approach, departing from well-managed and efficiently organised farming systems. Specific year effects, for example through weather influences, were avoided by using multi-year averages for crop yields and animal production. Trends in these averages were not taken into account. Data used apply to the physical environment in southern and eastern Flevoland. The soil is a calcareous marine loam soil (clay fraction 25-35%, pH-KCl 7.3-7.6, organic matter content 3-6%), reclaimed from the sea 40 years ago. During the growing period, depth of the groundwater table is around 1.5 m.

To assess the impact of mixing specialised farming systems on nutrient use efficiency, a nutrient balance approach was applied, considering nitrogen (N) and phosphorus (P), the two most problematic elements from an environmental point of view. All inputs were quantified, and only those outputs leaving the farm gate in useful products. The difference between total inputs and outputs in useful products is either lost to the environment or stored in soil reserves.

Labour requirements were calculated for each half-month period of the year for each of the farming systems, using normative task times (Anonymous, 1994a; 1995a). Annual labour availability amounts to 2 093 hours per full-time labourer

on the arable farm and 2 349 hours per full-time labourer on the dairy farm. A maximum labour availability per period was assigned to each half-month period of the year according to de Koeijer & Wossink (1992) for the arable farm and according to van Mensvoort (1993) for the dairy farm. For the mixed farming system, labour availability and labour requirements per period per farm were added. By confronting labour requirements and labour availability per period, the need for hiring labour was assessed.
Labour income was calculated as revenues minus fixed costs (buildings, machinery, land) and variable costs (costs of external inputs, contract labour, hired labour, etc.) for all three farming systems. Data to calculate revenues and fixed and variable costs were taken from Anonymous (1994a; 1995a).
Scope for reduced herbicide use in the mixed farming system was assessed by comparing crop rotations in the specialised farming systems and the mixed farming system with respect to weed-suppressing capacity. Scope for reduced pesticide use was assessed by examining (1) against which pests and diseases pesticides are applied in the specialised farming systems, and (2) whether the occurrence of these pests and diseases will be reduced in the mixed farming system.
Currently, mixed farming systems hardly exist in the Netherlands, which makes this study future-oriented. Hence, comparing specialised and mixed farming systems is only meaningful when considering specialised farming systems that can be expected to remain economically viable in the coming decade. Farm size is an important indicator of viability. The size of farms most recently issued by the government served as a criterion to separate farms with good future perspectives from those with less favourable perspectives. For arable farms this size was 65 ha, and for dairy farms 55 ha. The definitions of the three farming systems are given below. Important characteristics of both specialised farming systems are summarised in Table 2.1, and for the mixed farming system in Table 2.2.

Definition of the specialised arable farm

The Dutch Central Bureau of Statistics (CBS) provided data on crop areas on specialised arable farms >65 ha in southern and eastern Flevoland. Based on these data, a representative arable farm, with typical farm size and crop areas, was defined. The number of arable farms in the years 1995 and 1996 larger than 65 ha amounted to 111, with an average size of 80 ha. The following crop rotation was adopted: sugar beets (*Beta vulgaris* L.) (25%) - winter wheat (*Triticum aestivum* L.) (25%) - seed onions (*Allium cepa* L.) (12.5%) and grass seed (12.5%) - ware potatoes (*Solanum tuberosum* L.) (25%).

Nutrient balances were calculated using a target-oriented approach. First, total nutrient removal in crop products was calculated. Subsequently, the required nutrient inputs were calculated to realise this nutrient removal.

Crop yields were determined using 5-year averages as given in Anonymous (1994a). Standard N and P concentrations in marketable crop products were taken from Stouthart & Leferink (1992). Multiplying nutrient concentrations by crop yields resulted in nutrient removal in marketable crop products, from which total aboveground N-uptake was derived by dividing this by crop-specific N-harvest-indices, as given by Schröder *et al.* (1993). Based on data given by Schröder *et al.* (1993), Habekotté (1994) calculated crop-specific efficiencies with which crops utilise soil mineral N (defined as total aboveground N-uptake divided by available N) for situations with ample available N. These efficiencies were used to assess the required amounts of mineral N for the five crops in the rotation. P-requirements of the whole crop rotation were met using pig slurry. The P status of the soil was considered 'sufficient' in agricultural terms (van der Paauw, 1973). Annual P-input with pig slurry should equal P-removal in crop products from the whole rotation plus 9 kg P ha^{-1} yr^{-1}, the P-surplus allowed by the Dutch government (Anonymous, 1995b). To prevent soil structure damage, slurry at arable farms is applied in late summer, after early-harvested crops, i.e. winter wheat, grass seed, seed onions and ware potatoes. Application of pig slurry is followed by a catch crop (Italian ryegrass, *Lolium multiflorum* Lamk.).

Total available N is the sum of soil mineral N in spring, mineral N originating from decomposition of soil organic matter during the growing season, N from crop residues, N in pig slurry and, if required to meet crop demands, N in mineral fertiliser. Soil mineral N in spring was derived from unfertilised objects in a number of maize N-fertiliser trials on clay soils (Schröder, 1985; van der Schans *et al.*, 1995; van Dijk, 1996) and amounted to 64 kg ha^{-1}. Net mineralisation during the growing season is assumed to amount to 100 kg ha^{-1}. Carry-over of nitrogen via crop residues to following crops occurs after sugar beets (30 kg ha^{-1} via beet leaves) and grass seed (30 kg ha^{-1} via stubble and roots). After application of pig slurry in late summer combined with a catch crop, 35% of total N applied with slurry is assumed to be available for the next

main crop (Schröder *et al.*, 1996). The remainder is assumed to be either emitted to the environment, or stored in soil reserves.
Based on calculated labour requirements, it is assumed that one full-time labourer is present on the arable farm. Contract labour is used for sowing and harvesting sugar beets and grass seed, sowing onions, harvesting wheat and applying organic manure. The machine inventory on the arable farm is based on Wossink (1993).

Definition of the specialised dairy farm

CBS provided data on crop areas and numbers of animals present on specialised dairy farms >55 ha in southern and eastern Flevoland in the years 1995 and 1996. The Dutch Cattle Syndicate provided data on average annual milk production per cow in Flevoland. These data formed the basis for the definition of a representative dairy farm, with typical farm size, crop areas, number of cows and milk production per ha. The number of dairy farms in southern and eastern Flevoland in the years 1995 and 1996 larger than 55 ha was 36, with an average size of 72 ha. Of the total area used by these farms, 75% was used as grassland, 17% for maize (*Zea mays* L.) and 8% for arable crops. It is assumed here that on all land not used as grassland, maize is grown, i.e. 20 ha. Maize rotates with 40 ha of the grassland area, leaving 12 ha permanent grassland. Each year, 10 ha of ley is ploughed up, followed by maize for two successive years.
Grass dry matter yield was determined using empirical relationships between (i) N-availability and N-uptake and (ii) N-uptake and dry matter yield (Middelkoop & Aarts, 1991). The N-application rate on grassland was set to the economic optimum of 400 kg ha^{-1} yr^{-1} (Prins, 1983). Farm-produced cattle slurry was evenly distributed over the total grassland area and applied in three doses, the last one after the second cut. The N-fertiliser value of slurry was calculated using working coefficients as given by Anonymous (1994b). To arrive at an N-application rate of 400 kg N ha^{-1} yr^{-1}, additional mineral fertiliser was applied.
Herbage quality, animal energy requirements and feed intake by the animals were calculated using routines from a dairy farming model (van de Ven, 1996). Dairy cows graze only during the day. During the night 4.5 kg of dry matter of maize silage is fed indoors. Concentrates are fed only if necessary to meet

Table 2.1. Characteristics of the specialised farming systems.

Arable farm (80 ha, 1 full-time labourer)			Dairy farm (72 ha, 2 full-time labourers)		
Crop areas (ha) and marketable yields per ha (tons)			*Crop areas (ha) and dry matter yields per ha (tons)*		
• sugar beets	20	74.7	• permanent grassland	12	12.7
• winter wheat	20	8.5	• leys	40	12.7
• onions	10	57.1	• maize	20	13.6
• grass seed	10	1.4			
• ware potatoes	20	53.9			
Crop rotation			*Animal data*		
• sugar beets→winter wheat→seed onion and grass seed→ware potatoes			• dairy cows		143
			• yearlings		51
			• calves		53
			• animal density (cows ha^{-1})		2.75
			• concentrates (kg cow^{-1} yr^{-1})		1493
Timing of manure application			*Milk production data*		
• application of pig slurry and catch crop in late summer after early-harvested crops			• milk production per cow (kg FPCM yr^{-1})[1]		8233
			• milk production per ha (kg FPCM yr^{-1})		16352
			Timing of manure application		
			• application of cattle slurry on grassland in growing season		
Activities carried out with contract labour			*Activities carried out with contract labour*		
• sowing and harvest of sugar beets			• cultivation of maize		
• sowing and harvest of grass seed			• soil cultivation		
• sowing of onions			• resowing grassland		
• harvest of wheat			• application of slurry		
• application of slurry			• maintenance of ditches		

[1] *FPCM = fat and protein corrected milk*

energy and protein requirements. Feed rations in winter are based on grass and maize silage. By confronting total feed intake of the animal stock with on-farm roughage production, the need for purchased roughage was assessed.
Maize receives mineral fertiliser only. To assess the required dose, the same procedure as described for the crops at the arable farm was followed, however taking into account the nitrogen released in the first and second year after ploughing up grassland. Data on these amounts are scarce, especially for marine loam soils, after temporary grassland and for second and later years after ploughing. Here it was assumed that annual effective nitrogen accumulation under grassland amounts to 100 kg ha^{-1}. After ploughing up grassland, 40% of the nitrogen accumulated during the grassland period becomes available in the 1^{st} year and 20% in the 2^{nd} year (Biewinga *et al.*, 1992). The age of grassland ploughed up is 4 years, thus having accumulated 400 kg N ha^{-1}, 160 kg of which will become available for the 1^{st} year maize crop (similar to the amount obtained by Spiertz & Sibma, 1986) and 80 kg for the 2^{nd} year maize crop.
Based on calculated labour requirements, it is assumed that two full-time labourers are present on the dairy farm. Contract labour is used for manure application, all operations associated with the cultivation of maize (including sowing, spraying and harvesting), maintenance of ditches, resowing grassland and all soil cultivation practices.

Definition of the mixed farming system

As stated, mechanisms underlying the expected benefits of mixed farming systems are use of on-farm produced concentrates, more efficient use of animal manure and wider crop rotations. Using on-farm produced concentrates is, however, not considered in this paper, because it would imply different crop areas. Moreover, in a regional perspective, growing more fodder crops at the expense of arable crops and replacing imported feed ingredients, would not necessarily result in an improved nutrient balance of the farming system, as lower inputs with feed ingredients would largely be offset by reduced outputs in arable products.
A wider crop rotation was established by incorporating the total maize area and the maximum grassland area of the dairy farm into the crop rotation of the arable farm. As on the specialised dairy farm, 12 ha is permanent grassland.

Consequently, 40 ha of grassland can be incorporated into the rotation as ley. Ley is ploughed up in November after the fourth summer. Each year 10 ha of ley is sown after an early-harvested crop and 10 ha is ploughed up. The following crop rotation was adopted: onions (10 ha) - ley (1-4 years old, 4*10 ha) - ware potatoes (10 ha) - winter wheat (10 ha) - sugar beets (10 ha) - maize (10 ha) - ware potatoes (10 ha) - grass seed (10 ha) - winter wheat (10 ha) - maize (10 ha) - sugar beets (10 ha). To quantify the amounts of nitrogen available for crops in the rotation from decaying grass roots and stubble, the same rules of thumb as for the specialised dairy farm were applied. However, for the specialised dairy farm data were only given for the first two years after ploughing up grassland, whereas for the mixed farming system data for subsequent years are also required. Hence, it was assumed that 15% of the accumulated effective nitrogen becomes available in the 3rd year, 10% in the 4th year and 5% in each of the next three years (Biewinga *et al.*, 1992). As on the specialised dairy farm, 4-year old grassland has accumulated 400 kg N ha^{-1}, 160 kg of which will become available for the crop in the 1st year after ploughing, 80 kg in the 2nd year, 60 kg in the 3rd , 40 kg in the 4th and 20 kg in the 5th to 7th years.

As on the specialised arable farm, P-requirements of the whole crop rotation were met using slurry, however, cattle slurry being added to the pig slurry. On the specialised arable farm, slurry had to be applied in late summer, associated with a low N utilisation efficiency. In the mixed farming system, part of this slurry can be applied to grassland in the growing season. Application of slurry in late summer can thus be avoided by maximising slurry application on grassland. This slurry application strategy aims at accumulating P in the soil profile under grassland in rotation, such that P-requirements of crops grown after ploughing up grassland are met as much as possible. The maximum dose per cut was set to 30 m^3 of slurry, while per year a maximum of three doses can be applied, the last dose after the second cut. The N-fertiliser value of slurry was calculated in the same way as for the specialised dairy farm.

The cropping frequency of crops grown in the specialised farming systems is higher than in the mixed farming system, which for some crops in the specialised farming systems results in yield reductions, due to soil-borne pests and diseases. Based on Dutch long-term crop rotation experiments, Habekotté (1994) derived yield reduction factors as a function of cropping frequency for a number of crops (Table 2.3, with bold-printed numbers applying to the specialised farming systems). Because of reduced cropping frequencies, yield

reduction factors are absent in the mixed farming system. It is assumed that the higher-yielding crops in the mixed farming system have the same nutrient concentrations as in the specialised farming systems and that nutrients are taken up with the same (crop-specific) efficiencies.
In the mixed farming system, machinery of both specialised farms is combined.

Table 2.2. Characteristics of the mixed farming system.

Mixed farming system (152 ha, 3 full-time labourers)				
Crop areas (ha) and yields per ha (tons)			*Animal data*	
• sugar beets	20	85.4	• dairy cows	143
• winter wheat	20	8.5	• yearlings	51
• onions	10	57.1	• calves	53
• grass seed	10	1.4	• animal density (cows ha^{-1} grassl. + fodder crops)	2.75
• ware potatoes	20	61.9	• concentrates (kg cow^{-1} yr^{-1})	1493
• permanent grassland	12	12.7		
• leys	40	12.7		
• maize	20	14.8		
Crop rotation			*Milk production data*	
• onions (10 ha)→ley (4*10 ha; 1-4 years old)→ware potatoes (10 ha)→winter wheat (10 ha) →sugar beets (10 ha) →maize (10 ha)→ware potatoes (10 ha) →grass seed (10 ha)→winter wheat (10 ha) →maize (10 ha)→sugar beets (10 ha)			• milk production per cow (kg FPCM yr^{-1})	8233
			• milk production per ha grassl. + fodder crops (kg FPCM yr^{-1})	16352
Timing of manure application			*Activities carried out with contract labour*	
• maximum application of slurry on ley in growing season, remainder with catch crop after early-harvested crops			• sowing and harvest of sugar beets, grass seed and maize	
			• sowing of onions	
			• harvest of winter wheat	
			• application of slurry	
			• maintenance of ditches	

Table 2.3. Yield reduction factors as a function of cropping frequency (Habekotté, 1994). Yield reduction factors applicable to the specialised farming systems are printed bold.

	Cropping frequency						
	1:1	1:2	1:3	1:4	1:5	1:6	>1:7
Sugar beets	0.48	0.37	0.26	**0.13**	0.05	0.0	0.0
Ware potatoes	0.25	0.15	0.15	**0.13**	0.09	0.04	0.0
Maize	**0.13**	0.10	0.08	0.06	0.03	0.0	0.0

As a result, the mixed farming system is less dependent on contract labour. Hence, spraying of maize, re-sowing grassland and all soil cultivation practices that were carried out in contract labour on the specialised dairy farm, can be carried out with own machinery in the mixed system, provided available labour is not yet fully utilised. Contract labour is still used for sowing and harvest of sugar beets, grass seed and maize, sowing onions, harvest of winter wheat, manure application and maintenance of ditches, because the machinery for these activities is lacking on both specialised farms.

2.3 Results

Nutrient balances

Nutrient balances of the specialised farming systems and the mixed farming system are given in Table 2.4. Differences between the combined nutrient balance of both specialised farming systems and that of the mixed farming system are small. Nutrient output is somewhat higher in the mixed farming system, because of higher yields of sugar beets and ware potatoes. As crop nutrient requirements were calculated using a target-oriented approach and it was assumed that the higher-yielding crops in the mixed system take up nutrients with the same efficiency as in the specialised farming system, a higher nutrient output with crops in the mixed system requires higher inputs. Accordingly, P-requirements of the crop rotation in the mixed system are somewhat higher, explaining the higher pig slurry input. Because in the mixed farming system part of the pig slurry can be applied to grassland in the growing season, N in pig slurry is utilised more efficiently than in the specialised system, and a reduction in mineral fertiliser input was to be expected. However, even despite the higher N release in the mixed system after ploughing up grassland (400 kg N ha^{-1} grassland ploughed up vs. 240 kg at the specialised dairy farm), this is not the case: N input with mineral fertiliser is higher. This is related to the fact that the amount of pig slurry that could be applied to grassland is limited to 15% of all pig slurry applied (while the remainder still had to be applied in late summer), and to higher crop N requirements of sugar beets, ware potatoes and maize. As a result, differences in utilisation of N in pig slurry are small: per kg N applied in pig slurry in the specialised farming systems, i.e. the arable farm, 0.35 kg N is effective, whereas in the mixed farming system

Table 2.4. Nutrient balances of the specialised farming systems and the mixed farming system. All data are expressed in kg ha^{-1} yr^{-1}.

	Arable farm (80 ha)		Dairy farm (72 ha)		Total specialised (152 ha)		Mixed (152 ha)	
	N	P	N	P	N	P	N	P
Inputs								
pig slurry	147	37	0	0	78	20	81	21
art. fertiliser	89	0	161	1	123	0	126	0
roughage	0	0	46	7	22	3	20	3
concentrates	0	0	97	24	46	12	46	12
deposition	34	0	34	0	34	0	34	0
sundries	0	0	7	1	3	0	3	0
total inputs	270	37	345	33	306	35	310	35
Outputs								
crop products	145	29	0	0	77	15	82	16
milk/meat	0	0	102	19	48	9	48	9
Total outputs	145	29	102	19	125	24	131	25
Surplus	125	8	243	14	181	11	179	10
outputs/inputs	0.54	0.78	0.30	0.58	0.41	0.69	0.42	0.71

each kg of N in pig slurry results in 0.38 kg effective N. Roughage input is lower in the mixed farming system because of a higher maize yield, reducing the need to purchase maize. Inputs with concentrates, deposition and sundries do not differ between the systems, because it was assumed that these inputs were not affected by mixing specialised farming systems.
In the mixed farming system, the amount of pig and cattle slurry applied is tuned to the total P-removal in products. Within the specialised farming systems this holds only for the arable farm, whereas at the specialised dairy farm all slurry produced by the livestock is evenly distributed over the grassland area, neglecting P accumulation.

Labour requirements

In Table 2.5, for all three farming systems an overview is presented of annual labour availability, on-farm labour input, required hired labour, total labour requirements and labour surplus (calculated as available labour minus on-farm labour input). It shows that annually hired labour is 12% lower in the mixed farming system. This is due to the fact that if, for example, at the specialised dairy farm a labour shortage exists in period March-1, this can not be covered by a possible labour surplus from the specialised arable farm, and additional labour has to be hired. In a mixed farming system context, where at the dairy farm part the same labour shortage occurs in March-1, it is indeed possible to.

Table 2.5. Labour requirements and supply in the specialised farming systems and the mixed farming system. All data expressed in h yr^{-1}.

	Arable farm	Dairy farm	Total specialised	Mixed
Labour availability farmer(s)	2093	4698	6791	6791
On-farm labour input	1987	4424	6411	6585
Hired labour input (excl. contract labour)	652	316	968	851
Total labour requirements	2639	4740	7379	7436
Labour surplus	106	274	380	206

use labour from the arable farm part. On an annual basis, this results in a reduction of 117 hours of hired labour

The same mechanism also causes higher labour requirements in the mixed farming system: where in the specialised farming systems in a certain period contract labour is used, in the mixed farming system contract labour may be substituted by labour still available at the dairy farm part or the arable farm part, provided the required machinery is present. Consequently, cultivation and ploughing of the maize stubble, seedbed preparation for leys to be established and ploughing up of grassland can in the mixed farming system be carried out with own labour and machinery, where in the specialised farming systems these activities are carried out using contract labour.

Because of the higher on-farm labour input in the mixed farming system, the labour surplus is lower, or, in other words, available labour is used more efficiently.

Labour income

Labour income in the mixed farming system is about Dfl 500,-- ha^{-1} higher than that in the specialised systems (Table 2.6). This higher labour income results mainly from higher revenues, making up 70% of the increase in labour income,

Table 2.6. Costs, revenues and labour income in the specialised farming systems and the mixed farming system. All data are in Dfl ha^{-1} yr^{-1}.

	Arable farm	Dairy farm	Total specialised	Mixed
Fixed costs	3249	6049	4575	4575
Variable costs				
costs contract labour	538	987	751	669
costs hired labour	223	120	174	154
other variable costs	1986	3124	2525	2472
Total costs	5996	10281	8026	7870
Revenues	7393	13212	10149	10509
Labour income	1397	2931	2124	2639

rather than from lower costs. Higher revenues in the mixed farming system result from higher yields per ha of the profitable crops sugar beet and ware potato. Lower costs mainly originate from a more efficient utilisation of available labour, reducing contract labour costs (explaining 16% of the increase in labour income) and lower variable costs (explaining 10% and mainly originating from a reduced need to purchase maize).

Pesticides

In general, mown crops have a higher weed-suppressing capacity than root crops, mainly because their soil cover is higher. Especially the weed-suppressing capacity of grassland is high, because it is a very dense, multi-annual crop and regularly grazed or mown, preventing annual weeds to produce seed and depleting perennial weeds. Weeds can thus be suppressed by alternating crops with low weed-suppressing capacity with those with high weed-suppressing capacity (Vereijken *et al.*, 1994). As the share of mown crops in the rotation of the mixed farming system is higher than in the specialised arable farming system, in the longer term weed incidence in arable crops may be lower, reducing the need to apply herbicides. Empirical data supporting this are, however, lacking. For instance, van Dijk *et al.* (1996) monitored weed incidence in several grass - maize rotations on sandy soils, varying in length of the grassland period (0, 2 and 6 years). The rotations showed no differences with respect to emergence of weeds in maize after ploughing up grassland. Most important weeds that germinated were annual Chenopodium species. This was explained by the absence of stimulation of seed germination through soil cultivation in grassland, leaving the seed bank intact, and by the fact that seeds under an undisturbed grass sward remain viable for many years. In another long-term experiment, weed incidence was monitored in several rotations, with different shares of root crops. No differences among rotations were found with respect to the occurrence of annual weeds, but perennial dicotyledonous weeds tended to be more prominent in crop rotations with a high (>67%) share of dicotyledonous crops, irrespective of the ratio between mown and root crops in the rotation (Hoekstra & Lamers, 1993). Schotveld & Kloen (1996) studied weed incidence on 10 arable organic farms with rotations in which root crops alternate mown crops. They found that populations of perennial and particularly annual weeds increased in both mown and root

crops. Thus, alternating root crops and mown crops in a rotation does not necessarily result in reduced weed populations.
In conclusion, although in theory reduced weed incidence in the mixed farming system is expected, empirical data do not allow a quantitative assessment of the possible reduction in herbicide use.
The pesticides used in the specialised farming systems are all applied to control non-soil-borne pests and diseases like beetles, flies, aphids, thrips, mildew, leaf rust, yellow rust, leaf spot and wire worms and for haulm killing (Anonymous, 1994a; 1995a). Consequently, widening of crop rotations is not likely to influence the need to apply these pesticides.

2.4 Discussion

In this paper, agronomic, environmental and socio-economic effects of mixing a specialised dairy farm and a specialised dairy farm have been quantified. Calculations are based on a normative approach and should be considered as such. Under the assumptions made, the main agronomic effect of mixing is higher yields per ha of ware potatoes, sugar beets and maize. The main socio-economic effect is a 25% higher labour income per ha. Seventy percent of this increase is achieved through higher yields per ha of the profitable crops ware potato and sugar beet. The remaining 30% is the result of lower costs, due to a more efficient utilisation of available labour, reducing contract labour and hired labour costs and due to lower costs for purchasing maize. Environmental effects are limited. Differences between the combined nutrient balance of both specialised farming systems and that of the mixed farming system are small. Improved N use efficiency was to be expected in the mixed farming system, because pig slurry could be applied to grassland in the growing season, instead of in late summer. However, due to the ratio between grassland and arable crops and due to the relatively high cattle slurry production per ha of grass (related to the intensity of the dairy farm), the proportion of pig slurry that could be applied to grassland was limited to only 15%. Consequently, N use efficiency was hardly improved. Mixing specialised farming systems in Flevoland has no effect on the need to apply pesticides.

The overall conclusion is that a 25% higher labour income per ha can be attained without increasing environmental pollution as indicated by N and P surplus and pesticide input.
De Koeijer *et al.* (1995), using linear programming, maximised labour income for a specialised dairy farm, a specialised arable farm and the merger of both farms, i.e. a mixed farm. At their mixed farm, labour income per ha was 63% higher than the sum of that generated on both specialised farms. In this paper, the increase in labour income per ha at the mixed farm amounted 'only' to 25%. The major reason for the much higher increase at their mixed farm was a shift in land use towards more profitable crops at the expense of feed crops. Such a strategy is opportune at farm level, but not necessarily at regional or higher levels: if all farmers applied this strategy, prices of the more profitable crops would decrease and those of forage crops rise.
Contrary to the results in this paper and those of de Koeijer *et al.* (1995), Oskam (1996) concluded on the basis of an extensive statistical data analysis, that specialised dairy farms, characterised by a high milk production per ha forage crops, generate more income than less specialised ones, also per unit of N-surplus (i.e. the difference between N-inputs and useful N-outputs). However, since Oskam was comparing two groups of farms varying in intensity of land use, the statistical analysis not necessarily reflects a causal relationship between degree of specialisation and economic performance. Moreover, the higher income per unit of N-surplus is likely to be the result of a shift of part of their N-losses to the producers of purchased inputs (Aarts *et al.*, 1989).
Effects of mixing specialised farming systems were quantified starting from two specialised farms, each with a specific size. Starting from other farm sizes will yield different results. Should we have started from a specialised dairy farm half the size, with the same milk production per ha, but only one full-time labourer, the benefits of mixing would have been smaller. Cropping frequencies would have been lowered to a smaller extent, resulting in smaller yield increases of the profitable crops. Moreover, opportunities to apply pig slurry to grassland in the growing season would have been even more limited. No differences would occur with respect to utilisation of available labour: not only labour availability decreases, but also and to the same extent labour requirements. Finally, the increase in labour income would have been smaller, due to the smaller increases in yield per ha of profitable crops.
The opposite situation would occur when starting from a specialised arable farm half the size, but still with one full-time labourer. In that case the major

part of the pig slurry can be applied to grassland in the growing season, resulting in higher N use efficiency. Cropping frequencies of the arable crops would be lowered to an even larger extent, however not resulting in higher yields per ha, as yield reduction factors were already absent in the defined mixed farming system. Starting from a smaller arable farm would imply that more contract labour can be substituted by own labour. However, its cost-reducing effect would be limited, as in the defined mixed system the majority of contract labour costs is for activities for which the required machinery is lacking on both farms.

In this paper it is shown that in a mixed farming system it is possible to realise a higher income and reach higher production levels without increasing environmental pollution. These results raise the question to what extent farmers currently co-operate with neighbouring farms in a comparable way as in this paper. Although different forms of co-operation between farmers are not at all uncommon, quantitative data regarding this are not known to us. Whether farmers are inclined to co-operate intensively with other farmers, will be determined by their willingness to sacrifice part of their independence and accept the complexity of the arrangements needed to organise such increased co-operation. Furthermore, perspectives for mixed farming systems at regional level are determined by the future balance between integrating and differentiating forces. As stated earlier, a new integrating force is the need to enhance sustainability. While environmental advantages of the mixed farming system as defined in this paper were limited, drawing general conclusions regarding environmental aspects of mixing specialised farming systems is not yet possible, because we considered only two specific specialised farming systems. Key factor is the ratio between animal and arable production in the region, determining the extent to which crop rotations can be widened and the relative amounts of slurry that can be applied to grassland. Moreover, numerous other ways of mixing specialised farming systems are possible, e.g. involving other crops, animals and management options. Systematic model analysis, combining quantification of agro-ecological, environmental and socio-economic indicators for a wide range of production techniques and optimisation, seems a promising approach to the exploration and design of mixed farming systems.

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CHAPTER 3

Input-output coefficients for arable cropping, dairy farming and pig husbandry

3.1 Introduction

The modelling technique applied in this study is multiple goal linear programming (MGLP; Chapter 1). In the approach, farming systems are viewed as being composed of so-called activities, comprising sets of coherent operations, each set corresponding to a particular way of producing a crop or animal product. Each activity is characterised by so-called input-output coefficients. This chapter defines the agricultural activities considered in this study and eligible for adoption in farming systems. In addition, part of the input-output coefficients of each activity is quantified, notably agronomic coefficients. Defined agricultural activities refer to arable cropping (Section 3.2), dairy farming (Section 3.3) and landless pig production (Section 3.4).

3.2 Input-output coefficients of crop production activities

3.2.1 Definition criteria

A crop production activity is defined as a set of husbandry actions from land preparation until delivery of crop products. Many crop production activities are conceivable, each characterised by a unique set of contributions to the various goals and side-effects of agricultural land use. Crop production activities are formulated in a standardised way to allow generic formulation of objective functions and constraints (Schans, 1996). They are characterised by six definition criteria (Table 3.1). Each feasible combination of definition criteria represents a crop production activity `XC(gg,e,r,p,n,qq)` (unit: ha).
The first definition criterion `gg` refers to crop species. Arable crop species for which input-output coefficients are quantified include winter wheat (*Triticum aestivum* L.), onion (*Allium cepa* L.), sugar beet and fodder beet (*Beta vulgaris* L.), maize (*Zea mays* L.), ware potato (*Solanum tuberosum* L.), white cabbage (*Brassica oleracea* var. capitata (L.) Alef. var. alba DC) and green pea (*Pisum sativum* L.). Ware potato is assumed resistant to *Globodera*-nematodes and sugar beet and fodder beet to rhizomania. Grassland is included as a major feed crop. Input-output coefficients for grassland are quantified in Section 3.3, because it is associated with dairy farming for which a different set of definition criteria is used.

The second definition criterion `e` refers to soil disease status, that affects crop yield and is determined by the presence of soil-borne pests and diseases as influenced by the preceding crop. The third definition criterion `r` defines cropping frequency, affecting crop yield through crop-specific soil-borne pests and diseases. Cropping frequencies defined are in the range from 1:2 to 1:10, hence continuous cropping is not considered. However, two exceptions are grassland and maize, which can be cropped continuously, as commonly practised on Dutch dairy farms. The fourth definition criterion `p` defines whether a direct area payment is opted for. Direct area payments were introduced in 1992 as part of the Mac Sharry reforms for various crops, including winter wheat, maize and green pea. If direct area payment is opted for, 10% of the area for which payment is received has to be put under set-aside. The fifth definition criterion `n` deals with the nitrogen (N) supply of crops. Given the economically optimal crop yield as determined by the values for definition criteria `e` and `r`, N requirements are quantified for 100, 95 and 90% of that yield level. Thus, N requirements for the 95 and 90% yield level constitute sub-optimal N input levels, further reducing yields. Definition criterion `n` does not exist for green pea, because in this study pea is not fertilised with N. The sixth definition criterion `qq` refers to the product of harvest of a crop. It only applies to crop species for which more than one harvesting regime exists, i.e. maize, beet and winter wheat. Maize can be harvested for silage making or as corn-cob-mix (CCM), beet as sugar beet (excluding beet leaves) or as fodder beet (excluding beet leaves) and winter wheat for bread-making (excluding straw), as feed grain (including straw) or for making whole crop cereal silage.

Each crop production activity `XC(gg,e,r,p,n,qq)` is characterised by an unique set of input-output coefficients. The only input quantified in this chapter is crop N requirement. Quantified outputs are crop yields, N leaching and denitrification losses, organic N balances and P removal in crop products. Inputs and outputs are quantified on a per crop per ha per year basis.

In Section 3.2.2, the procedures followed to quantify the effects of the individual definition criteria on input-output coefficients are explained, exemplified for ware potato. In Section 3.2.3 parameters for the other arable crop species are given.

Table 3.1. Definition criteria and numerical values of the indices for arable crop production activities.

1. Crop species (definition criterion gg; maxgg=13)

gg=	1: 6:	grassland
gg=	7:	maize
gg=	8:	ware potato, *Globodera*-resistant cultivar
gg=	9:	sugar beet or fodder beet, Rhizomania-resistant cultivar
gg=	10:	onion
gg=	11:	winter wheat
gg=	12:	green pea
gg=	13:	white cabbage

2. Soil disease status due to preceding crop (definition criterion e; maxe varies per crop species)

e=	1:	no damage
e=	2:	damage level 1
e=	3:	damage level 2
e=	4:	etc.

3. Cropping frequency (definition criterion r, maxr=9)

r=	1:	cropping frequency 1:2
r=	2:	cropping frequency 1:3
r=	3:	cropping frequency 1:4
r=	4:	cropping frequency 1:5
r=	5:	cropping frequency 1:6
r=	6:	cropping frequency 1:7
r=	7:	cropping frequency 1:8
r=	8:	cropping frequency 1:9
r=	9:	cropping frequency 1:10

4. Direct area payment (definition criterion p; maxp=2)

p=	1:	not opting for direct area payment
p=	2:	opting for direct area payment; 10% of the area under set-aside

5. Nitrogen application rate (definition criterion n; maxn=3)

n=	1:	100% of economically optimal yield
n=	2:	95% of economically optimal yield
n=	3:	90% of economically optimal yield

6. Product of harvest (definition criterion qq; maxqq varies per crop species)

qq=	1:	maize harvested for silage making, beet harvested as sugar beet (excluding leaves), winter wheat harvested for bread-making (excluding straw)
qq=	2:	maize harvested as corn-cob-mix, beet harvested as fodder beet (excluding leaves), winter wheat harvested as feed grain (including straw)
qq=	3:	winter wheat harvested as whole crop cereal silage

3.2.2 Parameterisation of ware potatoes

Impact of soil-borne pests and diseases

The design of a crop rotation influences incidence levels of soil-borne pests and diseases and thus potato tuber yields (Scholte, 1989; de Koning *et al.*, 1992; Struik & Bonciarelli, 1997). The effect of an individual pathogen on tuber yield depends on its incidence level in the potato crop, as determined by the preceding crop and the cropping frequency of potato, and on the susceptibility of the potato crop to that pathogen. Incidence levels and susceptibility of the potato crop have been quantified in close co-operation with crop experts (L.P.G. Molendijk and J.G. Lamers, Institute of Applied Research for Arable Farming and Field Production of Vegetables, PAV, Lelystad), considering all major pathogens in the region under study: nematodes (*Globodera rostochiensis*, *G. pallida* and *Heterodera schachtii*), fungi (*Verticillium dahliae, Rhizoctonia solani, Phoma spp., Gaeumannomyces graminis, Pseudocercosporella herpotrichoides, Drechslera tritici-repentis, Sclerotinia sclerotiorum, Plasmodiophora brassica, Helicobasidium brebissonii* and *Sclerotium cepivorum*), actinomycetes (*Streptomyces spp*.) and viruses (beet necrotic yellow vein virus). Tables were constructed that describe (a) pathogen incidence levels as 'left behind' by preceding crops for individual combinations of preceding crop and pathogen, and (b) yield reductions in potato as a function of pathogen incidence levels for individual combinations of potato and pathogen. Four incidence levels were distinguished, i.e. 'high', 'medium', 'low' and 'absent'. By combining tables (a) and (b), yield reductions and relative yields for individual potato-preceding crop-pathogen combinations were derived. Relative yields for individual potato-preceding crop-pathogen combinations have been lumped to relative yields for individual potato-preceding crop combinations by multiplication of the relative yields as determined by each pathogen. Multiplication of relative yields is a compromise between summing the individual yield reductions - which would lead to a lower lumped relative yield - and using only the minimum of the individual relative yields - which would lead to a higher lumped relative yield -. This compromise is chosen to account for the rather low knowledge level regarding interactions between pests and diseases and their effects on crop yields. Relative yields calculated in this way for individual potato-preceding crop combinations are represented in the values for definition criterion e (Table 3.2). Preceding crops

either result in 0 or 10% yield reduction, hence two values for definition criterion `e` suffice for potato.
Additionally, tables have been constructed that describe relative tuber yields in potato as a function of cropping frequency for individual combinations of potato and pathogen. These were lumped to relative tuber yields as a function of cropping frequency, again by multiplication of the relative yields as determined by single pathogens. Lumped tuber yield reductions as a function of cropping frequency are given in Table 3.3. They refer to a *Globodera*-resistant potato cultivar and are represented in definition criterion `r`. The pathogens causing the yield reductions are *Verticillium dahliae, Streptomyces spp.* and *Rhizoctonia solani AG3*.

Nitrogen requirements

Given the potato tuber yield as determined by the values for definition criteria `e` and `r`, N requirements have been quantified for 100, 95 and 90% of the associated economically optimal yield level. N requirements refer to fertiliser-N that needs to be available for uptake in mineral form during the growth period of the potato crop. Whether that is from mineral fertilisers or from organic fertilisers is irrelevant here, but determined in the MGLP model (Chapter 4). N requirements were quantified by fitting individual N-response experiments to a model called QUADMOD (ten Berge *et al.*, 2000). QUADMOD quantifies the response of crop yield *Y* to N-input *A* on the basis of the partial responses of crop yield *Y* to N-uptake *U*, *Y(U)*, and of N-uptake *U* to N-input *A*, *U(A)*.

Table 3.2. Yield reductions in Globodera-resistant ware potato as influenced by preceding crops.

Value definition criterion `e`	Preceding crops	Yield reduction (%)	Pathogen(s)
1	onion, winter wheat, grass	-	-
2	maize, sugar / fodder beet, green pea, cabbage	10	Rhizoctonia solani AG2-2

Table 3.3. Yield reductions in Globodera*-resistant ware potato as a function of cropping frequency.*

Cropping frequency	> 1:6	1:5	1:4	1:3	1:2
Value definition criterion r	5 - 9	4	3	2	1
Yield reduction (%)	0	6	12	20	31

Both responses are quantified over two domains, using different functions *U(A)* and *Y(U)* in each domain. Domain I applies to the lower range of N availability, with a linear *U(A)* function. Domain II is in the upper range of N availability, using a parabolic function *U(A)*. The transition between the two domains in a given N response experiment occurs at the so-called 'critical point' and is governed by the N concentration in the crop. Hence, up to the critical point, in domain I, the apparent N recovery (ANR) is constant, in domain II ANR gradually decreases with increasing N-input. Functions *U(A)* and *Y(U)* are characterised by seven independent parameters, each with a biophysical meaning:

Y_{max} : yield plateau, representing maximum crop yield as limited by environmental conditions but under abundant N-availability;
S : N uptake derived from indigenous soil N;
ρ_{ini} : initial apparent N recovery, i.e. ANR below the critical point;
α_{min} : minimum N concentration in crop biomass;
α_{crit} : N concentration in crop biomass at critical point;
α_{max} : maximum N concentration in crop biomass;
γ : crop yield at critical point, expressed as a fraction of Y_{max}.

QUADMOD parameter sets have been estimated for 49 N-response experiments with ware potato, using the maximum likelihood method. Fitted N-response experiments for potato are given in Appendix 1. Only Dutch experiments on clay soils were used, in which neither organic fertilisers nor catch crops were used. The fitting procedure resulted in 49 parameter sets for ware potato. The average response of a potato crop was calculated by averaging the parameter values of the individual experiments, provided these experiments met two criteria (ten Berge *et al.*, 2000). The first criterion is that the experiment covered at least part of domain I, i.e. that the experiment included N-limited objects.

This criterion was operationalised by setting the requirement to experiments that the ratio of lowest to highest observed tuber yield was below 0.75. Sets not meeting this requirement were omitted for the calculation of mean values for ρ_{ini}, α_{min}, α_{crit} and γ. The second criterion is that crop yield in an experiment indeed reached a plateau in domain II. The difference between the highest observed N-uptake and the highest fitted N-uptake (the latter calculated as α_{max}*Y_{max}) was used as an indicator for this criterion. Its value should not exceed 25 kg N ha^{-1}. Larger values of this indicator imply that estimates of the parameter values α_{max} and Y_{max} are based on extrapolations from observations in the upper end of domain II, causing the parameters Y_{max}, α_{max}, α_{crit} and γ to be unreliable. Note that N-response experiments should meet both criteria to qualify for the assessment of mean values for α_{crit} and γ.

Mean parameter values for ware potato and the number of valid experiments on which these means are based are given in Table 3.4. Figure 3.1 shows the individual observations in all 49 N-response experiments and the fitted average functions *U(A)* and *Y(U)*.

One of the QUADMOD parameters is Y_{max}, denoting the maximum yield as determined by environmental conditions and under abundant N-availability. Values for Y_{max} of each experiment are determined by many factors, such as the weather in the experimental year, the potato cultivar used, soil properties, cropping history of the experimental fields and the 'age' of the experiment. All these experiment-specific factors are reflected in the calculated mean Y_{max}. Therefore, the mean Y_{max} as derived from the N-response experiments may not be representative for the maximum yield of a potato crop cultivated in a specific present-day rotation. To avoid underestimation of Y_{max}, the fitted mean Y_{max} was replaced by a new value, i.e. the potato yield predicted for the year 2003, only if the latter yield was higher. The prediction of potato yield in the year 2003 is based on the time trend in annual potato yield. This time trend was

Table 3.4. Mean values of QUADMOD parameters for ware potato and the number of N-response experiments on which these means are based.

Parameter	Y_{max}	S	ρ_{ini}	α_{min}	α_{crit}	α_{max}	γ
Mean value	12810 (40)	86 (49)	0.56 (35)	0.007 (35)	0.011 (28)	0.017 (40)	0.92 (28)

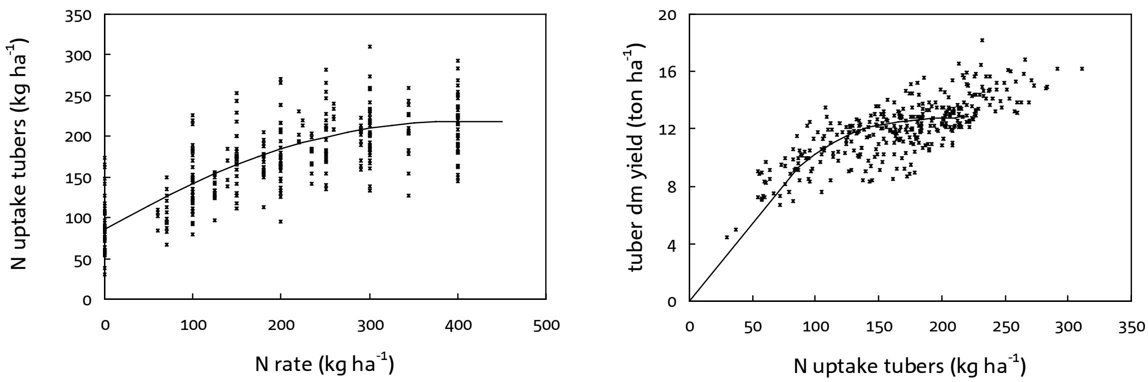

Figure 3.1. *N-application rate vs. N-uptake (left) and N-uptake vs. crop yield (right) as observed in 49 N-response experiments with ware potato, including fitted average responses* U(A) *and* Y(U).

calculated from historical data on average yields at commercial farms in Dutch clay regions in the period 1946-1996 (Anonymous, 1946-1996). The trend can be described with the equation $y = 123x + 5\ 263$ ($R^2_{unadjusted}$ 0.86), where y denotes tuber dm yield in kg and x the year number since 1946. Using this equation, the predicted potato tuber yield in the year 2003 amounted to 12.3 tons. With fitted mean Y_{max} amounting to 12.8 ton tuber dm, N-response experiments used do not result in underestimation of potato yield. Hence, substitution of fitted mean Y_{max} by predicted yield proved not necessary for ware potato and fitted mean Y_{max} was taken as the attainable yield. The attainable yield is the yield of a rain-fed potato crop cultivated in the absence of yield reducing effects due to preceding crop (e=1) or due to cropping frequency ($r \geq 5$) under abundant nutrient supply. Subsequently, the attainable yield was corrected for yield reductions as determined by the values for definition criteria r and e, assuming all other QUADMOD parameters constant. This implies that as many new QUADMOD-parameter sets, i.e. N response curves, were defined as there were combinations of e and r influencing attainable potato yield, these sets only differing with respect to parameter Y_{max}. Hence, for ware potato 2*5 (see Tables 3.2 and 3.3) response curves were defined. The five response curves used with e=1 (no yield reduction due to the preceding crop) are shown in Figure 3.2.

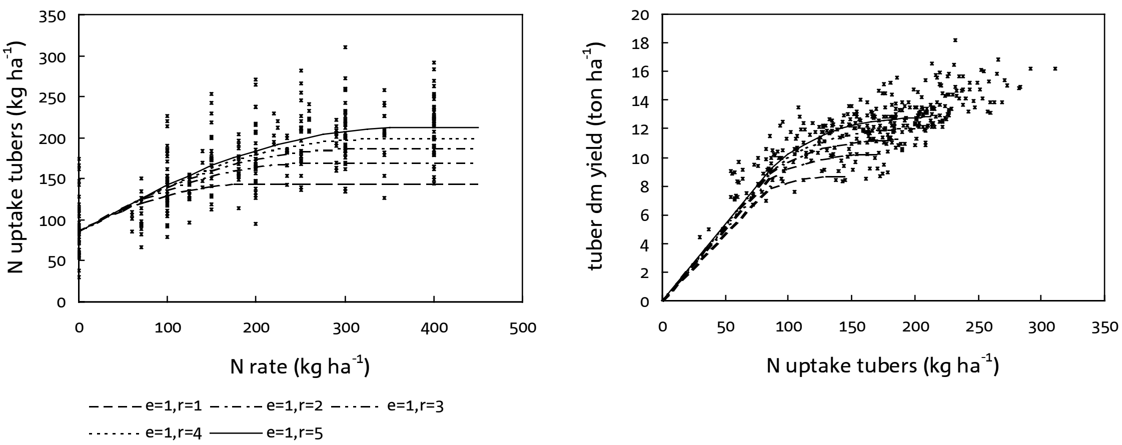

Figure 3.2. U(A) *(left) and* Y(U) *(right) functions for ware potato corrected for cropping frequency* `r` *with soil disease status* `e`*=1 (no yield reduction due to the preceding crop). Observations from 49 N-response experiments with ware potato are included.*

Using the appropriate *U(A)* and *Y(U)* functions for each combination of soil disease status `e` and cropping frequency `r`, N fertiliser requirements, N uptake and associated ANRs can be calculated for the three yield levels defined in Table 3.1 (definition criterion `n`). Table 3.5 shows the results for 1:2 (`r`=1), 1:4 (`r`=3) and 1:6 (`r`=5) potato crops cultivated on a soil with disease status `e`=1. Economically optimal N rates (`n`=1) are calculated on the basis of the price ratio of fertiliser-N (€ 0.51 per kg; Anonymous, 1997a) and crop produce (€ 0.53 per kg tuber dm; Anonymous, 2001). Resulting economically optimal potato yields were always more than 99% of corrected Y_{max} values.

Nitrogen balances and nitrogen losses

N balances and losses for all potato production activities are quantified separately for the growth period and the winter period. As for quantification of potato N requirements, N balances and losses quantified below refer to a base situation, i.e. assumed to occur when crops are fertilised with N in mineral form only. Whether crops are partly fertilised with organic fertilisers is selected in the MGLP model. Implications of application of organic fertilisers for N balances and losses are quantified in Chapter 4.

Table 3.5. Tuber dm yield, N requirement, N uptake in tubers and ANR for three yield levels n of a 1:2 (r=1), 1:4 (r=3) and 1:6 (r=5) ware potato crop cultivated on a soil with disease status e=1. (Relative N requirements between brackets).

Cropping frequency / target yield	Values definition criteria r and n	Tuber yield (kg dm ha^{-1})	N fertiliser requirement		N uptake tubers (kg N ha^{-1})	ANR
Cropping frequency 1:2						
1.0*economically optimal	r=1, n=1	8696	125	(100)	136	0.40
0.95*economically optimal	r=1, n=2	8262	25	(20)	100	0.55
0.90*economically optimal	r=1, n=3	7827	0	(0)	86	-
Cropping frequency 1:4						
1.0*economically optimal	r=3, n=1	11253	205	(100)	175	0.44
0.95*economically optimal	r=3, n=2	10690	78	(38)	129	0.55
0.90*economically optimal	r=3, n=3	10127	44	(21)	110	0.57
Cropping frequency 1:6						
1.0*economically optimal	r=5, n=1	12784	250	(100)	199	0.45
0.95*economically optimal	r=5, n=2	12145	109	(44)	146	0.56
0.90*economically optimal	r=5, n=3	11505	70	(28)	125	0.56

N losses during the growth period are quantified according to the following balance sheet equation:

$$N_{loss} = N_{mins} + N_{atms} + M_{nets} + N_{fix} + N_{fert} - N_{prod} - N_{cropres} - N_{res}$$

where,

N_{loss} = N lost from the soil-crop system during the growth period of potato;
N_{mins} = mineral N present in the 0-100 cm soil layer in spring (1 March);
N_{atms} = atmospheric N input in the growth period;
M_{nets} = net mineralisation between 1 March and harvest date in the 0-25 cm soil layer;
N_{fix} = N from symbiotic N_2 fixation;
N_{fert} = fertiliser N input;
N_{prod} = N in harvested potato tubers;

$N_{cropres}$ = N in crop residues;
N_{res} = residual soil mineral N in the 0-100 cm soil layer after harvest of potato.

N_{atms} is set to 75% of the annual atmospheric N input (30 kg N ha^{-1}) and amounts to 23 kg N. N_{mins} is set to 40 kg N ha^{-1}. Annual net mineralisation in the 0-25 cm soil layer is based on field measurements in a calcareous silty loam soil as reported by Bloem *et al.* (1994) and de Vos & Heinen (1999) and set to 120 kg N ha^{-1} yr^{-1}. With harvest date of ware potato set to 1 October and assuming a distribution of mineralisation over the year according to Rijtema (in Lammers, 1983; Appendix 3), M_{nets} amounts to 94 kg N ha^{-1} yr^{-1}. Values for N_{atms} and M_{nets} as calculated here apply to all potato production activities. N_{fix} is zero. N_{fert} and N_{prod} depend on the appropriate *U(A)* and *Y(U)* functions as determined by the values of definition criteria `e`, `r` and `n`. N harvest index (NHI) of potatoes is set to 0.85 (Biemond & Vos, 1992; Vos, 1997). Hence, $N_{cropres}$ is calculated as (N_{prod} / 85) * 15. Typical values for N_{res} were derived from literature (Neeteson & Wadman, 1991; Neeteson, 1994; Schröder *et al.*, 1996; Vos & van der Putten, 2000; van Enckevort *et al.*, 2002). Based on these sources it is assumed that N_{res} values for a potato crop given 250, 120 and 0 kg fertiliser N, in the absence of yield reducing effects due to preceding crop and/or cropping frequency (i.e. `e`=1 and `r`≥5, further referred to as production activities *without* rotation effects) amount to 100, 45 and 45 kg N ha^{-1}, respectively. N_{res} values as applicable in this study for such potato production activities (e.g. the 1:6 potato crop in Table 3.5), are determined by interpolation. Accordingly, N_{res} values for all potato production activities without rotation effects are set to 100, 45 and 45 kg N ha^{-1} for `n`=1, `n`=2 and `n`=3, respectively. If yield reductions do occur (i.e. `e`=2 and/or `r`≤5, further referred to as production activities *with* rotation effects), both input and output terms are smaller (Table 3.5) and N_{res} levels assumed lower. The difference between total available N and N in crop product and crop residues (i.e. the mineral N load of the soil in autumn, calculated as $N_{mins} + N_{atms} + M_{nets} + N_{fix} + N_{fert} - N_{prod} - N_{cropres}$) served as an indicator for N_{res} levels. This indicator was calculated for all production activities defined. For each yield level `n`, the values for production activities without rotation effects were set to 100%. Subsequently, again for each yield level `n`, N-loads for potato production activities with rotation effects were expressed as a fraction of N-loads for production activities without rotation effects. Multiplication of these fractions with N_{res} values for potato production activities without rotation effects for each target yield level n, yielded N_{res} values for potato production activities with rotation effects. The minimum N_{res} value is set to 45 kg ha^{-1}. N_{loss} closes the balance. It refers to N lost from the soil-crop system in the period between early spring and harvest date of potatoes. N_{loss} was partitioned over denitrification and leaching in a 2:1 ratio (Addiscott & Powlson, 1992). Calculated N balances and losses for the growth period for the potato production activities in Table 3.5 are given in Table 3.6a.

N losses during the winter period are quantified according to the following balance sheet equation:

$$N_{losw} = N_{res} + M_{neta} + N_{atmw} + M_{netw} - N_{mins+}$$

where,

N_{losw} = N lost from the soil-crop system during the winter period;
N_{res} = soil mineral N in the 0-100 cm soil layer after harvest of potatoes;
M_{neta} = net mineralisation in early autumn in the 0-25 cm soil layer, i.e. between harvest date and 1 November;
N_{atmw} = atmospheric N input in the winter period;
M_{netw} = net mineralisation in the winter period, i.e. between 1 November and 1 March;
N_{mins+} = soil mineral N in the 0-100 cm soil layer in the following spring.

N_{atmw} is set to 25% of the annual atmospheric N input and amounts to 8 kg N. Values for M_{neta} (9 kg N) and M_{netw} (17 kg N) were calculated using the same assumptions as for the growth period. N_{mins+} is calculated from the linear regression equation $N_{mins+} = 0.46*(N_{res}+M_{neta}) + 26$ ($R^2_{unadjusted}$ 0.54). (Figure 3.3). N_{losw} closes the balance. Partitioning of N_{losw} over leaching and denitrification differs from that for the growth period. In winter, denitrification losses are assumed lower due to lower temperatures, and N_{losw} is partitioned over denitrification and leaching in a 1:2 ratio. N balances and losses for the winter period for the potato production activities of Table 3.5 are given in Table 3.6b.

The balance sheet equations for the growth period and the winter period are combined to calculate N balances on an annual basis (Table 3.6c). Inputs are N_{mins}, annual net mineralisation ($M_{net} = M_{nets} + M_{neta} + M_{netw}$), annual deposition ($N_{atm} = N_{atms} + N_{atmw}$), N_{fix} and N_{fert}. Outputs are N_{prod}, $N_{cropres}$, annual N losses ($N_{los} = N_{loss} + N_{losw}$) and N_{mins+}. N_{los} is partitioned over leaching and denitrification as explained above. The fraction of denitrification losses lost as N_2O is set to 8% (based on Velthof & Oenema, 1997) and the remainder is assumed to emit as N_2.

Table 3.6c also shows organic N balances (N_{orgbal}). Output term of the organic N balances is annual net mineralisation, M_{net}. Input term is N contained in potato crop residues, $N_{cropres}$. Hence, $N_{orgbal} = N_{cropres} - M_{net}$. N_{orgbal} is negative for all potato production activities (Table 3.6c), implying that additional organic N inputs are required if M_{net} is to be maintained. Additional organic N inputs can be supplied by organic fertilisers or by crop residues from other crops in the rotation. Both these inputs are dealt with in the MGLP model (Chapter 4).

Phosphorus output

P output of each potato production activity is calculated by multiplication of tuber yield and P content of tubers. Tuber P content is assumed constant for all production activities, at 2.26 kg P per ton dm (Stouthart & Leferink, 1992).

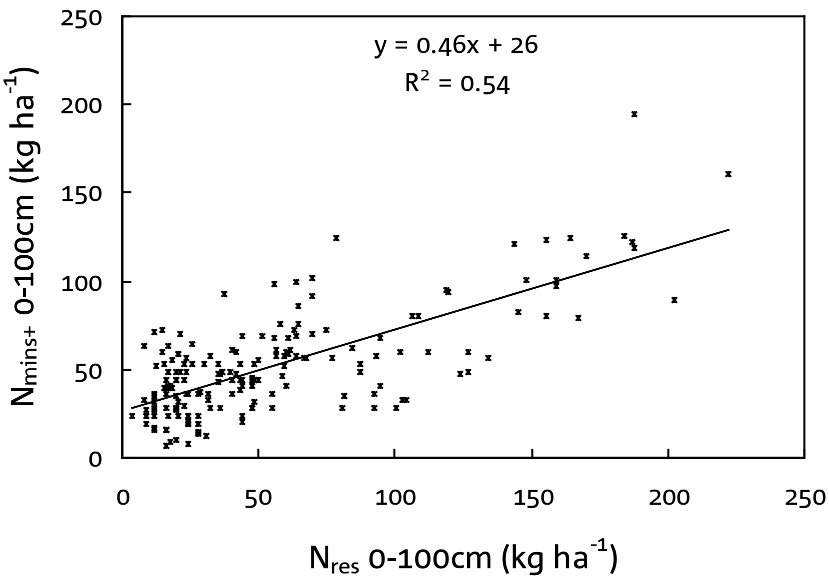

Figure 3.3. *Soil mineral N in the 0-100 cm soil layer in spring (N_{mins+}) as affected by soil mineral N in the 0-100 cm soil layer in the preceding autumn (N_{res}). All measurements apply to clay soils and to objects in which neither organic fertilisers nor catch crops were used (Hengsdijk, 1992; Schröder, 1985; K. Zwart, Alterra Research Institute, unpublished data). N_{res} data apply to measurements shortly after harvest of various crops (maize, ware potato, sugar beet and cereals). N_{mins+} data were determined between February and April.*

Table 3.6. *N balances and losses for the growth period (Table 3.6a), the winter period (Table 3.6b) and on an annual basis (Table 3.6c) of 1:2, 1:4 and 1:6 ware potato crops cultivated on a soil with disease status e=1 at three yield levels n.*

Table 3.6a. *N balances and losses for the growth period.*

Cropping frequency	1:2 (r=1)			1:4 (r=3)			1:6 (r=5)		
Target yield	n=1	n=2	n=3	n=1	n=2	n=3	n=1	n=2	n=3
Inputs									
N_{mins}	40	40	40	40	40	40	40	40	40
N_{atms}	23	23	23	23	23	23	23	23	23
M_{nets}	94	94	94	94	94	94	94	94	94
N_{fert}	125	25	0	205	78	44	250	109	70
Total inputs	282	182	157	362	235	201	407	266	227
Outputs									
N_{prod}	136	100	86	175	129	110	199	146	125
$N_{cropres}$	24	18	15	31	23	19	35	26	22
N_{res}	70	45	45	89	45	45	100	45	45
Total outputs	230	163	146	295	197	174	334	217	192
N_{loss}	51	20	10	65	38	25	73	48	34
denitrification	34	13	7	43	25	17	49	32	23
leaching	17	7	3	22	13	8	24	16	11

Table 3.6b. *N balances and losses for the winter period.*

Cropping frequency	1:2 (r=1)			1:4 (r=3)			1:6 (r=5)		
Target yield	n=1	n=2	n=3	n=1	n=2	n=3	n=1	n=2	n=3
Inputs									
N_{res}	70	45	45	89	45	45	100	45	45
M_{neta}	9	9	9	9	9	9	9	9	9
N_{atmw}	8	8	8	8	8	8	8	8	8
M_{netw}	17	17	17	17	17	17	17	17	17
Total inputs	104	79	79	123	79	79	134	79	79
Outputs									
N_{mins+}	63	51	51	72	51	51	76	51	51
Total outputs	63	51	51	72	51	51	76	51	51
N_{losw}	41	27	27	51	27	27	57	27	27
denitrification	14	9	9	17	9	9	19	9	9
leaching	27	18	18	34	18	18	38	18	18

Table 3.6c. N balances and losses on an annual basis.

Cropping frequency	1:2 (r=1)			1:4 (r=3)			1:6 (r=5)		
Target yield	n=1	n=2	n=3	n=1	n=2	n=3	n=1	n=2	n=3
Inputs									
N_{mins}	40	40	40	40	40	40	40	40	40
M_{net}	120	120	120	120	120	120	120	120	120
N_{atm}	30	30	30	30	30	30	30	30	30
N_{fert}	125	25	0	205	78	44	250	109	70
Total inputs	315	215	190	395	268	234	440	299	260
Outputs									
N_{prod}	136	100	86	175	129	110	199	146	125
$N_{cropres}$	24	18	15	31	23	19	35	26	22
N_{mins+}	63	51	51	72	51	51	76	51	51
N_{los}	92	47	38	117	65	53	130	76	62
denitrification	48	22	16	61	34	26	68	41	32
leaching	44	25	22	56	31	27	62	34	30
Total outputs	315	216	190	395	268	233	440	299	260
N_{orgbal}	-96	-102	-105	-89	-97	-101	-85	-94	-98

3.2.3 Parameterisation of other crops: winter wheat, sugar beet, fodder beet, white cabbage, maize, onion and pea

Impact of soil-borne pests and diseases

The impact of soil-borne pests and diseases on crop yields are quantified following the same procedures as for ware potato, considering the same pathogens. Hence, for each crop, tables were constructed that describe yield reductions of crops as influenced by preceding crops, and tables that describe yield reductions as a function of cropping frequency. Yield reductions are based on expert knowledge, which in turn is based on experience gained in several long-term rotation experiments (Hoekstra & Lamers, 1993; Huiskamp & Lamers, 1992; Huiskamp, 1990). Yield reductions as influenced by preceding crops are given in Table 3.7 and those as influenced by cropping frequency in Table 3.8. Yields of sugar beet, fodder beet, pea and winter wheat are affected by preceding crops. Yield reduction in sugar and fodder beet preceded by maize,

Table 3.7. Yield reductions in sugar beet, fodder beet and green pea as influenced by preceding crops.

Crop	Value definition criterion e	Preceding crop	Yield reduction (%)	Pathogen(s)
Beet	1	grassland	-	-
	2	winter wheat	5	Rhizoctonia solani AG2-2
	3	ware potato, onion	25	id.
	4	maize, green pea	50	id.
	5	cabbage	61	id. and Heterodera schachtii
Pea	1	all crops, except ware potato	-	-
	2	ware potato	10	Sclerotinia sclerotiorum

Table 3.8. Yield reductions in sugar beet, fodder beet, green pea and maize as a function of cropping frequency.

Crop	Cropping frequency							Pathogen(s)
	>1:7	1:6	1:5	1:4	1:3	1:2	1:1	
Maize	0	0	0	0	0	0	13	Peronosporales
Beet	0	6	8	12	19	36	n.a.	Rhizoctonia Solani AG2-2, Helicobasidium brebissonii, BNYVV, Het. schachtii
Peas	0	5	5	10	10	25	n.a.	Sclerotinia sclerotiorum

green pea and white cabbage is more than 50%, hence these crop sequences are excluded. Maize, onion and white cabbage can be preceded by any crop without negative effects on yields. Cropping frequency influences yields of sugar and fodder beet, pea and maize. For maize, a 13% yield reduction applies only if it is continuously cropped (Huiskamp & Lamers, 1992). The yield reduction is attributed to root rot, caused by fungi and possibly also bacteria.

Apart from having direct effects on crop yields, pests and diseases may additionally prevent crops to be cultivated with high frequencies or combined in one rotation. Cultivation of white cabbage and onion at 1:2 and 1:3 frequency is excluded, to prevent infection with fungi *Sclerotium cepivorum* and *Helicobasidium brebissonii* that, once present, are highly persistent. Additionally, cultivation of sugar beet or fodder beet with white cabbage in one rotation is excluded for cropping frequencies higher than 1:6. Reason is that white cabbage serves as a host crop for *Heterodera schachtii*, causing serious yield reductions in sugar beet and fodder beet.

Nitrogen requirements

N response experiments for sugar beet, fodder beet, onion, maize, winter wheat and white cabbage were fitted to QUADMOD. Fitted N response experiments are given in Appendix 1. The fitting procedure resulted in mean QUADMOD-parameter sets for each crop, describing the average partial responses of crop yield *Y* to N uptake *U*, *Y(U)*, and of N uptake *U* to N input *A*, *U(A)*. Mean parameter values per crop are given in Table 3.9. To prevent experiment-specific factors determining attainable yield levels, mean values of Y_{max} for each crop are replaced by crop yields predicted for the year 2003, if the latter were higher. Predictions of crop yields in 2003 were calculated from linear regression equations, describing trends in average yields attained at commercial farms in Dutch clay regions (Anonymous, 1946-1996). Hence, the attainable yield for each crop is defined by either mean Y_{max} or the prediction of crop yield in 2003. Subsequently, attainable yields are corrected for yield reductions as determined by values for definition criteria `e` and `r`. Accordingly, for each crop, N response curves are defined for each combination of `e` and `r` affecting yield. For example, for sugar beet the number of variants of definition criteria `e` and `r` affecting yield equals 3 and 6, respectively. Hence, for sugar beet 3*6 response curves have been defined. Response curves of all crops are given in Figure 3.4 with `e` set to 1, combined with all observations of all N response experiments fitted to QUADMOD.
Using the appropriate functions *Y(U)* and *U(A)* for each combination of `e` and `r` affecting attainable yield, N fertiliser requirements to reach the three yield levels `n` can be calculated, as well as associated N uptakes and ANRs. Results for all crops cultivated on `e`=1 soils are given in Appendix 2. Economically optimal N rates were derived from price ratios of fertiliser-N and crop produce.

Resulting economically optimal crop yields were always more than 99% of corrected Y_{max} values.
Green pea is not fertilised with N in this study and therefore no N response curve is defined. Alternatively, N uptake in grains of green pea is calculated as the product of grain yield and N content. The attainable grain yield in 2003 was calculated from the time trend in annual grain yield at commercial farms. N content of grain dm was fixed at 3.9% (Jensen 1986, 1987). Grain yields of pea cultivated on e=1 soils and associated N uptakes are given in Appendix 2.

Table *3.9.* *Mean values of QUADMOD parameters of arable crops and the number of N-response experiments on which these means are based*[1].

Crop	Y_{max}		S		ρ_{ini}		α_{min}		α_{crit}		α_{max}		γ	
Maize	15457	(7)	93	(14)	0.62	(8)	0.007	(11)	0.010	(3)	0.013	(7)	0.94	(3)
Sugar beet	71389	(13)	76	(24)	0.28	(7)	0.0010	(7)	0.0012	(7)	0.0017	(13)	0.91	(7)
Fod. beet	15387	(6)	91	(12)	0.38	(5)	0.006	(6)	0.0076	(6)	0.0112	(6)	0.94	(6)
W. cabbage	99874	(9)	132	(12)	0.71	(14)	0.0026	(14)	0.0032	(8)	0.0036	(9)	0.92	(8)
Onion	65025	(11)	92	(12)	0.50	(5)	0.0015	(5)	0.0019	(5)	0.0023	(11)	0.96	(5)
W. wheat	7061	(15)	87	(21)	0.53	(15)	0.015	(15)	0.021	(10)	0.024	(15)	0.91	(10)

[1] *Maize: aboveground dm yield, aboveground N uptake; Winter wheat: dm yield grains, N uptake grains; Onion: fresh yield bulbs, N uptake bulbs and foliage; Sugar beet: fresh beet yield adjusted to a sugar content of 16%, N uptake beets. Fresh beet yields adjusted to a sugar content of 16% (in kg ha*$^{-1}$*) were calculated from measured yields (in kg ha*$^{-1}$*) using the equation* $y = x + x$*(sugar-% - 16)*0.085 (Neeteson & Wadman, 1987). N uptake in beets (in mmol kg*$^{-1}$ *fresh beet) was calculated from their* α*-amino-N content (in mmol kg*$^{-1}$ *fresh beet) using the equation* $y = 2.22x + 66$ ($R^2 = 0.74$) *(pers. comm. T. Huijbregts, IRS) and subsequently converted to N uptake in beets in kg ha*$^{-1}$*. Fodder beet: beet dm yield, N uptake beets. White cabbage: fresh marketable yield, aboveground N uptake.*

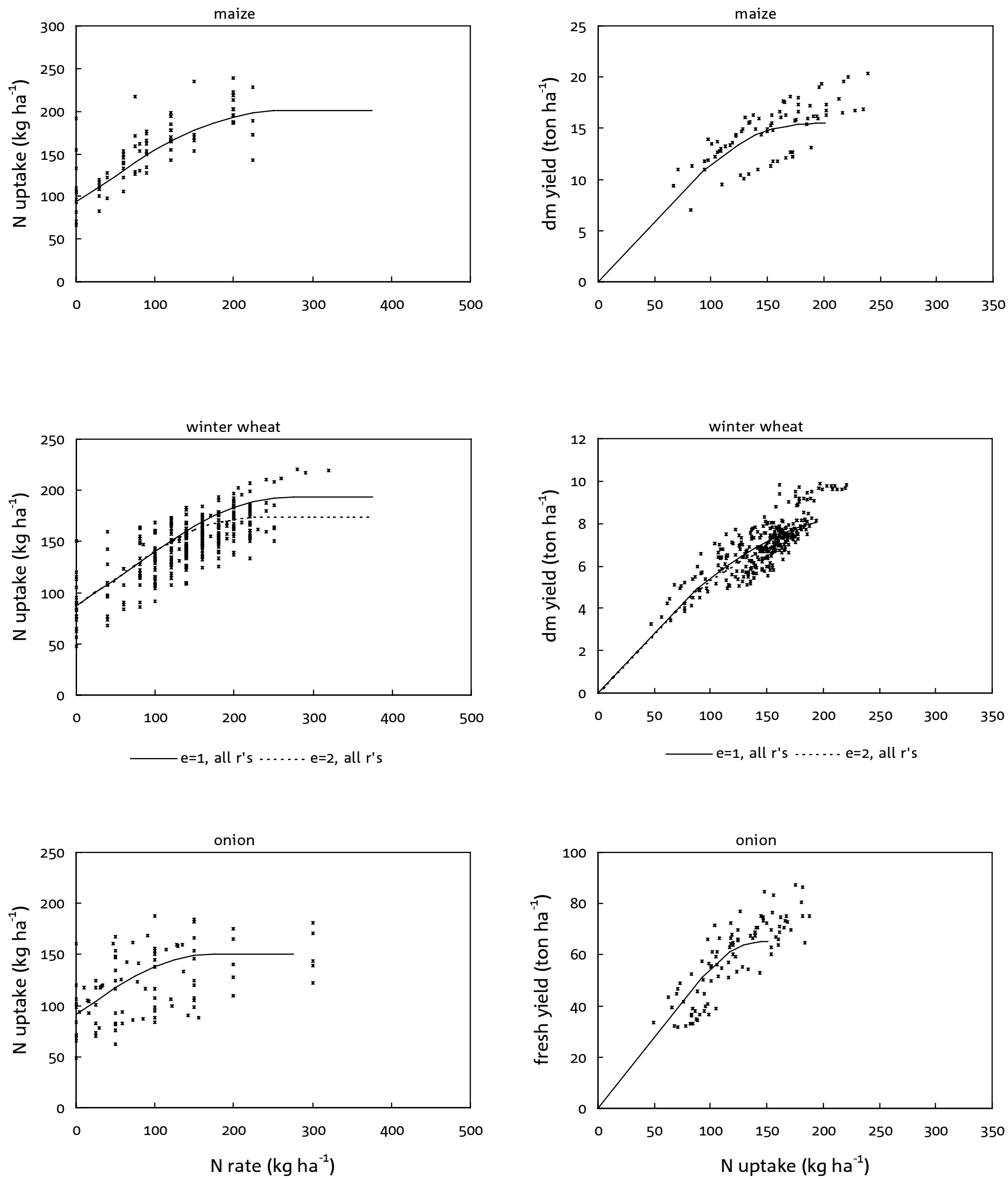

Figure 3.4.

U(A) (left column) and Y(U) (right column) functions for maize, winter wheat, onion, sugar beet, fodder beet and white cabbage corrected for cropping frequency r *and soil disease status* e*. Observations from all N-response experiments are included. (Maize: aboveground dm yield, aboveground N uptake; Winter wheat: dm yield grains, N uptake grains; Onion: fresh yield bulbs, N uptake bulbs and foliage).*

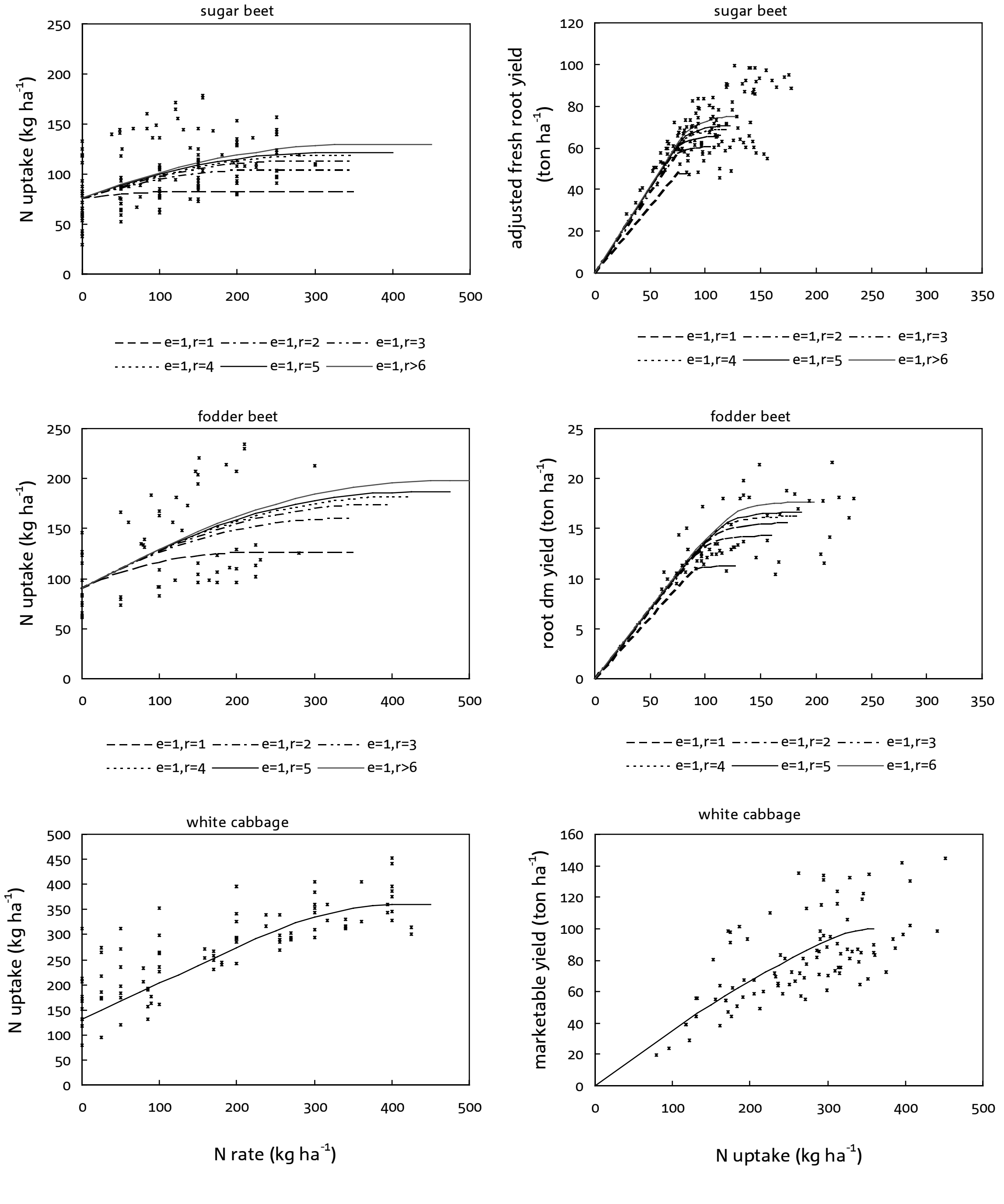

Figure 3.4 (continued).

U(A) *(left column) and* Y(U) *(right column) functions for maize, winter wheat, onion, sugar beet, fodder beet and white cabbage corrected for cropping frequency* `r` *and soil disease status* `e`*. Observations from all N-response experiments are included. (Sugar beet: fresh beet yield adjusted to a sugar content of 16% (Neeteson & Wadman, 1987), N uptake beets. Fodder beet: beet dm yield, N uptake beets. White cabbage: fresh marketable yield, aboveground N uptake).*

Nitrogen balances and losses

As for ware potato, N balances and losses are quantified separately for the growth period and the winter period for each crop, using identical balance sheet equations. Values of N_{mins}, N_{atms}, N_{atmw}, M_{netw} and M_{net} used for potato are applied to all crops. Derivation of crop-specific values for M_{nets}, M_{neta}, N_{fix} (only for green pea), $N_{cropres}$ and N_{res} is given in Appendix 3. Values for M_{nets} and M_{neta} depend on the harvest date of each crop. Values for $N_{cropres}$ and N_{res} for each crop were derived from literature. Values of N_{fert} and N_{prod} for each crop follow from the appropriate *U(A)* and *Y(U)* functions. N_{mins+} is calculated from the linear regression equation in Figure 3.3. N balances resulting from all calculations and assumptions are given in Table 3.10 for 1:6 crops cultivated on a soil with disease status e=1.

Phosphorus output

P outputs of crop production activities refer to P that is removed from the field, as determined by definition criterion qq. P contents of crop products (Appendix 4) are assumed fixed for all production activities.

3.2.4 Discussion

N response curves

Figures 3.2 and 3.4 show that the response of each crop to N strongly varies between sites and years. Sources of variation are numerous, including weather in the experimental year and soil properties. The procedures followed here in calculating N response curves for each crop neglect most of these sources of variation.

Apparent N recoveries (ANRs) of arable crops are calculated according to the difference method and using functions *Y(U)* and *U(A)*. ANRs of a selection of the potato production activities are given in Table 3.5 and those of the other crops in Appendix 2. In general, ANRs found are in agreement with values reported in literature.

Table 3.10. N balances on an annual basis for 1:6 crops cultivated at three yield levels n on a soil with disease status e=1. Winter wheat straw and beet leaves are left in the field.

	maize			sugar beet			fodder beet			white cabbage			winter wheat			onion			pea
	n=1	n=2	n=3	n=1	n=2	n=3	n=1	n=2	n=3	n=1	n=2	n=3	n=1	n=2	n=3	n=1	n=2	n=3	-
Inputs																			
N_{mins}	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
N_{atm}	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
M_{net}	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
N_{fert}	142	81	61	181	59	25	197	94	70	376	249	218	206	151	120	124	54	37	-
N_{fix}	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	215
Total inputs	332	271	251	371	249	215	387	284	260	566	439	408	396	341	310	314	244	227	405
Outputs																			
N_{prod}	174	143	131	116	92	82	161	127	118	178	154	143	185	166	151	110	94	87	190
$N_{cropres}$	21	21	21	84	63	53	69	54	51	178	154	143	85	80	75	71	55	51	57
N_{mins+}	58	48	45	40	37	36	43	40	39	54	45	40	56	54	53	71	61	60	85
N_{los}	79	59	55	130	57	43	114	63	52	155	87	82	69	41	31	62	35	29	73
denitrification	41	32	30	43	6	1	38	12	7	93	52	50	35	17	11	25	10	6	27
leaching	38	28	25	47	22	17	43	25	21	62	36	32	34	24	20	38	24	22	47
ammonia emission	-	-	-	40	30	25	33	26	24	-	-	-	-	-	-	-	-	-	-
Total outputs	332	271	252	370	249	214	387	284	260	565	440	408	395	341	310	314	245	227	405
N_{orgbal}	-99	-99	-99	-36	-57	-67	-51	-66	-69	58	34	23	-35	-40	-45	-49	-65	-69	-63

ANR in potato tubers at the highest yield level $n=1$ is 0.45. ANR at the two lower yield levels n is 0.56. MacDonald *et al.* (1997) applied recommended rates (about 225 kg N) to potato at several sites in the UK and found an average recovery of 0.49 in tubers. Saoud *et al.* (1992) applied recommended rates to potato in Belgium in 1985 (180 kg N) and 1986 (150 kg N) and found ANRs of 0.21 and 0.49, respectively. The low ANR in 1985 coincided with high rainfall during the growing season. Neeteson (1989) analysed 96 potato trials on sand, loam and clay soils and found ANRs ranging between 0.33 at recommended N rates and 0.50 at reduced N rates. These ANRs are lower than calculated in this study, but may be explained by the use of slurries and green manures in more than half of Neeteson's trials, including in 0N treatments, the N content of which was only partly accounted for (Neeteson & Zwetsloot, 1989).

ANR in aboveground crop parts of maize is 0.57 at the highest yield level and 0.62 at the lower two yield levels. Van Dijk & Brouwer (1998) found ANRs in trials in Flevoland of 0.55 (200 kg N), 0.58 (120 kg N) and 0.58 (90 kg N). Schröder *et al.* (1998) report ANRs from 0.53 at optimum N rates (159 kg N) to 0.61 at a lower rate (119 kg N).

ANR in bulbs and foliage of onion is 0.47 at the highest yield level and 0.50 at the lower two yield levels. These ANRs are somewhat higher than recoveries reported by Greenwood *et al.* (1992), who, based on partly the same experiments, predict ANRs of 0.38, 0.42 and 0.44 in bulbs and foliage of onion fertilised with 145, 88, and 68 kg N.

In the N response experiments with winter wheat, measurements of N uptake referred to uptake in grains. N uptake in winter wheat straw was calculated assuming a NHI of 0.77 for all N application rates (Anonymous, 1997b; Darwinkel, 1998). Using this NHI, ANR in winter wheat grains and straw amounts to 0.62 at the highest yield level and 0.68 at the two lower yield levels. Similar ANRs have been reported by MacDonald *et al.* (1997), Powlson *et al.* (1986) and Powlson *et al.* (1992), although ANRs show considerable variation between sites and years.

In the N response experiments with sugar beet, neither N uptake in roots nor in leaves was directly measured. N uptake in roots was calculated from measured α-amino-N contents. N uptake in leaves was estimated, assuming a NHI of 0.46 for unfertilised objects and 0.42 for N application rates exceeding 90 kg N ha^{-1} (van der Beek & Wilting, 1994). NHI's for intermediate application rates were determined by interpolation. Based on these data, ANRs in sugar beet roots and leaves were 0.62 at the highest yield level n and 0.77 at the two lower levels.

Allison *et al.* (1996) found recoveries to range between 0.59 at high N application rates (> 150 kg N) and 0.63 at lower N application rates (< 60 kg N). Recoveries as found by Neeteson & Ehlert (1989) in various experiments with sugar beet crops fertilised at recommended rates were rather high, i.e. in the range 0.62-0.83. Van der Beek & Wilting (1994) found relatively low recoveries: 0.41 at recommended N rate (128 kg N) and 0.47 at sub-optimal N rate (90 kg N). The relatively large variation in ANR of sugar beet as reported in literature might be related to many possible sources of error involved in quantifying N uptake in roots and leaves.

ANR in white cabbage was 0.60 at the highest yield level and 0.70 at the two lower yield levels. Everaarts (1993) gives an overview of ANRs for white cabbage found in various studies conducted outside the Netherlands. At moderate N levels (100-150 kg N), ANR was in the range 0.60-0.70; at higher application rates (200-300 kg N), ANR decreased to 0.37-0.63. Compared to these findings, ANRs found in this study are relatively high. This may be due to high white cabbage yields in some of the N response experiments used.

Three yield levels `n` as influenced by N application rate were defined for each combination of crop `gg`, soil disease status `e` and cropping frequency `r`. The highest yield level for each combination was the yield at economically optimal N rate (`n`=1), calculated on the basis of QUADMOD functions *Y(U)* and *U(A)* and the price ratio of fertiliser-N and crop produce. The two N-limited yield levels (`n`=2 and `n`=3) constituted 95 and 90% of the calculated economically optimal yield. Calculated N requirements for crops cultivated without rotation effects are given in Table 3.11, together with economically optimal N rates as recommended in practice to farmers (van Enckevort *et al.*, 2002). Calculated economically optimal N rates are consistent with recommended economically optimal N rates. One exception, however, is white cabbage. Calculated economically optimal N rate for that crop exceeds recommended optimal N rate by almost 100 kg N ha^{-1}. The much higher calculated optimal rate is caused by high yields in some of the N response experiments used. The range of economically optimal N application in white cabbage, as assessed in various studies, is 200-500 kg ha^{-1} (Everaarts & de Moel, 1998). Calculated optimal rate in this study is within that range.

Table 3.11 shows that, while crop yields are still 95 and 90% of economically optimal yields, N rates are drastically reduced. For example, N application rate

Table 3.11. Calculated economically optimal and sub-optimal N rates (with relative N rates between brackets) for crops cultivated without rotation effects (this study), and economically optimal N rates as recommended in practice (van Enckevort et al.*, 2002).*

	1.0*economically optimal yield (n=1)		0.95*economically optimal yield (n=2)		0.90*economically optimal yield (n=3)		recommended economically optimal N rate
ware potato	250	(100)	109	(44)	70	(28)	245
sugar beet	181	(100)	59	(33)	25	(14)	140
fodder beet	197	(100)	94	(52)	70	(39)	150
white cabbage	376	(100)	249	(66)	218	(58)	280
winter wheat	206	(100)	151	(73)	120	(58)	220
onion	124	(100)	54	(44)	37	(30)	110
maize in rotation	142	(100)	81	(57)	61	(43)	155

for the 95% yield level of ware potato is only 44% of N application rate at economically optimal yield. Relatively high yields at drastically reduced N rates were also found by Neeteson (1989) for ware potato and sugar beet: applying 50% of recommended N rates to potato (128 kg N) and sugar beet (49 kg N), yields were reduced by only 4%. When potato and sugar beet were not fertilised at all, yield reductions were 20 and 16%, respectively. Schröder *et al.* (1998) found 11 and 16% yield reduction in silage maize given 50 (79 kg N) and 37% (59 kg N) of optimal N rate (159 kg N). These yield reductions are higher than yield reductions in sub-optimally fertilised maize in this study.

Nitrogen leaching losses

N losses as quantified in this study for crops cultivated without rotation effects are given in Table 3.6 (ware potato) and Table 3.10 (all other crops). N losses refer to situations where crops are fertilised with mineral N only. Quantification is entirely based on an empirical approach, using many assumptions and estimates. Hence, N losses should be considered as rough estimates. Key assumptions concern annual net mineralisation and the partitioning of total N losses over denitrification and leaching.

Annual NO_3-N leaching losses under crops cultivated at economically optimal N rates (n=1) increase from 34 to 62 kg N ha^{-1} in the order winter wheat → onion → maize → fodder beet → sugar beet → pea → white cabbage → ware potato. Based on leaching losses as quantified in this study, crops may be split into three groups. The first group comprises winter wheat, onion and maize, showing similar, relatively low leaching losses. NO_3-N leaching losses in sugar beet, fodder beet and pea are intermediate. White cabbage and ware potato are in the third group, with high leaching losses.

In the study area, all agricultural land is subsurficially drained. Hence, the major part of N emissions from agricultural soils occurs via tile drains. In studies in which these emissions from arable cropping systems have been quantified (de Vos, 1997; van den Eertwegh, 2002), leaching losses are calculated as the product of measured nitrate concentrations in tile drain effluent and total drainage volume, the latter calculated from a water mass balance. De Vos (1997) quantified N loads in subsurface drainage water from an 'integrated' arable cropping plot, with reduced N inputs, in five consecutive winters. Depending on meteorological conditions, leaching varied over the years between 0 and 50 kg N ha^{-1} yr^{-1}. Over a 4-year crop rotation period (with crops ware potato, spring wheat, sugar beet and spring barley), 110 kg N ha^{-1} was annually applied as fertiliser and 28 kg N ha^{-1} leached, i.e. about 25% of applied fertiliser-N. Van den Eertwegh (2002) quantified total-N leaching losses for a catchment area at a commercial arable farm in eastern Flevoland in two consecutive seasons. Averaged over the two seasons, total-N leaching was 60 kg ha^{-1}, of which 55 kg as NO_3-N. Corresponding 4-year average N application rate, calculated over a full rotation cycle, was 230 kg N ha^{-1}, about 35% of which was applied in animal manure. Hence, also in the latter study, 25% of applied N leached.

A crop rotation from this study, with e.g. ware potato, winter wheat, sugar beet and onion at yield level n=1 would require 165 kg N ha^{-1} yr^{-1}, with leaching amounting to 41 kg N ha^{-1} yr^{-1} (25% of applied fertiliser-N). The same crop rotation with reduced N inputs, at yield level n=2, annually requires 76 kg N as fertiliser, in which 24 kg N would leach, i.e. 32% of applied fertiliser.

3.3 Input-output coefficients of milk production activities

3.3.1 Definition criteria

The two core activities in Dutch dairy farming are the cultivation of grass and the conversion of nutrients and energy contained in roughage, fodder crops and concentrates into milk and meat. Input-output coefficients of milk production activities should therefore cover a wide range of fodder crop production and feed utilisation methods. The characterisation of production activities for feed crops other than grass was presented in Section 3.2. Table 3.12 summarises the definition criteria for grass production and utilisation activities considered in this study and largely based on van de Ven (1996). The first definition criterion `nn` refers to N application rate on grassland, ranging from 50 to 400 kg, with increments of 50 kg per ha. The second definition criterion `bb` defines the grazing system. The extremes are zero grazing on one end and day-and-night grazing on the other, with day grazing as an intermediate system. For zero grazing and day grazing, two variants were formulated, i.e. with and without maize silage in the summer ration of cows. The third definition criterion, `yy`, refers to cattle type. The fourth definition criterion refers to milk production per animal, for which three levels have been defined. The fifth definition criterion defines the herbage supply level, `cc`. Herbage supply level is defined as the relative herbage intake level of cows, given their energy requirements and maximum herbage intake. At a herbage supply level of 1.0, concentrates are supplemented, only if required to meet energy requirements. At a herbage supply level of 0.9 and 0.8, concentrates replace 10 and 20%, respectively, of the herbage on a dm basis. The sixth definition criterion, `ff`, defines the stage at which grass for conservation is harvested and the product of conservation. Grass can be ensiled, made into hay or artificially dried.

Combinations of definition criteria `yy`, `bb`, `nn`, `cc` and `mm` refer to milk production activities `XG(yy,bb,nn,cc,mm)` (unit: ha) in which animals are included, consuming roughage feeds and concentrates and producing milk, meat and slurry. Inputs of these milk production activities, quantified in this chapter, are N and concentrate requirements in the grazing season. Quantified outputs are annual milk production, ammonia emission from pasture, annual N leaching and denitrification losses, N and P excretion in slurry in the grazing season, organic N balances and P balances. Combinations of `ff` and `nn` refer to

roughage production activities `XF(ff,nn)` (unit: ha) for conserved grass, hence without animals. For these activities, the only input quantified in this chapter is N requirement. Quantified outputs are dm yield of conserved grass products, nutritional values of these products, ammonia emission from pasture, annual N leaching and denitrification losses and organic N and P balances. Combinations of land allocated to milk production activities `XG(yy,bb,nn,cc,mm)` and roughage production activities `XF(ff,nn)` constitute a dairy farming system. The selection of combinations is arranged in the MGLP model.
As for crop production activities, inputs and outputs are quantified for a base situation, i.e. where grassland is fertilised with N in mineral form only. Whether grassland is partly fertilised with organic fertilisers is selected in the MGLP model. Implications of application of organic fertilisers are quantified in Chapter 4, as are other agronomic aspects of dairy farming systems, such as ammonia emission from the stable and manure storage, winter feed supply, winter feed requirements of the dairy herd and N and P excretion in slurry in winter.
Inputs and outputs of milk and roughage production activities have been quantified with an annual mass balance model called GRASMOD (van de Ven, 1992; van de Ven, 1996). This model was originally developed for dairy farming systems on sandy soils. For the present study, technical relationships underlying GRASMOD have been adapted to clay soils. The general outline and structure of GRASMOD have been described extensively elsewhere (van de Ven, 1996). Below, focus is on the 'translation' of technical relationships from sandy soils to clay soils.

3.3.2 Dry matter and N yield in grassland

The yield level at which grass is harvested is different for the various grassland utilisation methods defined in Table 3.12. Grass for conservation is cut at a harvestable yield of 4 000 kg dm (for silage or hay) or at 3 000 kg (for silage or artificially dried grass). Under a zero grazing system, grass is cut at 2 300 kg harvestable dm, while under grazing systems, animals are put into the pasture at a harvestable yield of 1 700 kg dm. On a seasonal basis, cutting frequency increases as the harvested yield per cut is lower. Cutting frequency determines the number of periods with reduced growth due to defoliation, hence total

Table 3.12. Definition criteria and numerical values of the indices for grass production and utilisation techniques, based on van de Ven (1996).

1. Nitrogen application rate grassland (definition criterion nn; maxnn=8)

nn=	1:	50
nn=	2:	100
nn=	3:	150
nn=	4:	200
nn=	5:	250
nn=	6:	300
nn=	7:	350
nn=	8:	400

2. Grassland utilisation method (definition criterion bb; maxbb=4)

bb=	1:	zero grazing, no maize supplementation
bb=	2:	zero grazing, supplementation with maize silage
bb=	3:	day grazing, supplementation with maize silage
bb=	4:	day-and-night grazing, no maize supplementation

3. Animal category (definition criterion yy; maxyy=3)

yy=	1:	dairy cow (> 2 years)
yy=	2:	calf (0-1 year)
yy=	3:	yearling (1-2 year)

4. Milk production level (definition criterion mm, maxmm=4)

mm=	1:	0
mm=	2:	6 500
mm=	3:	8 000
mm=	4:	10 000

5. Herbage supply level (proportion of maximum herbage supply; definition criterion cc; maxcc=3)

cc=	1:	1.0
cc=	2:	0.9
cc=	3:	0.8

6. Product of conservation of grass and dry matter yield at cutting (definition criterion ff, maxff=4)

ff=	1:	hay (4 000 kg)
ff=	2:	grass silage (4 000 kg)
ff=	3:	grass silage (3 000 kg)
ff=	4:	artificially dried grass (3 000 kg)

Table 3.13. *Mean values of QUADMOD parameters of grass and the number of N-response experiments on which these means are based.*

Parameter	Y_{max}	S	ρ_{ini}	α_{min}	α_{crit}	α_{max}	γ
Mean value	15454 (8)	135 (17)	0.86 (17)	0.019 (17)	0.029 (8)	0.041 (8)	0.89 (8)

annual dm production decreases with increasing cutting frequency (van de Ven, 1996; Sibma & Alberda, 1980; Sibma & Ennik, 1988). N uptake in grassland is far less determined by cutting frequency (Sibma & Ennik, 1988). Hence, in GRASMOD the response of dm yield to N application is the result of the combined effects of (1) N application on N uptake in grassland and of (2) N uptake on dm yield for harvesting regimes at 1 700, 2 300, 3 000 and 4 000 kg dm.
N response experiments with grass on clay soils were fitted to QUADMOD similarly to those for arable crops. Likewise, the average response of grassland to N was calculated by averaging QUADMOD-parameter sets of 17 individual N response experiments. Experiments used to calculate the average parameter set are given in Appendix 1. Only Dutch experiments on clay soils were used, considering treatments with mineral fertiliser only. Values of average QUADMOD parameters are given in Table 3.13. Individual observations in each of the experiments and the fitted average response are plotted in Figure 3.5.

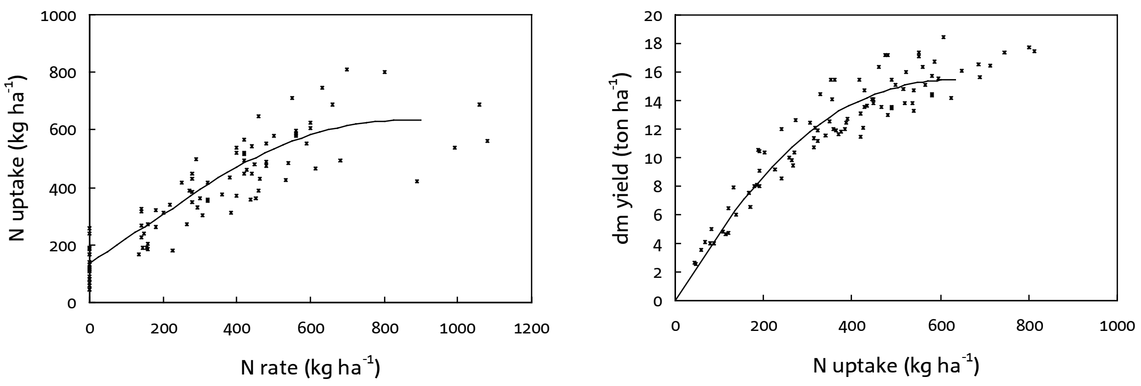

Figure 3.5. *N input vs. N uptake (left) and N uptake vs. dm yield (right) as observed in N response experiments with grass, including fitted response.*

The fitted average N uptake at each N input level (Figure 3.5a) was applied to all four cutting frequencies defined. The effect of cutting frequency on dm yield was taken into account by applying the relative differences between dm yields for the four harvesting regimes as calculated for sandy soils by van de Ven (1992). To this end, an average cut weight was assigned to the fitted average response in Figure 3.5, calculated as the average over all experiments and over all N treatments. Based on the average cut weight in the experiments, relationships for the defined cut weights were derived. In Figure 3.6, the resulting relationships between N uptake and dm yield at four harvesting frequencies on clay soils are given.

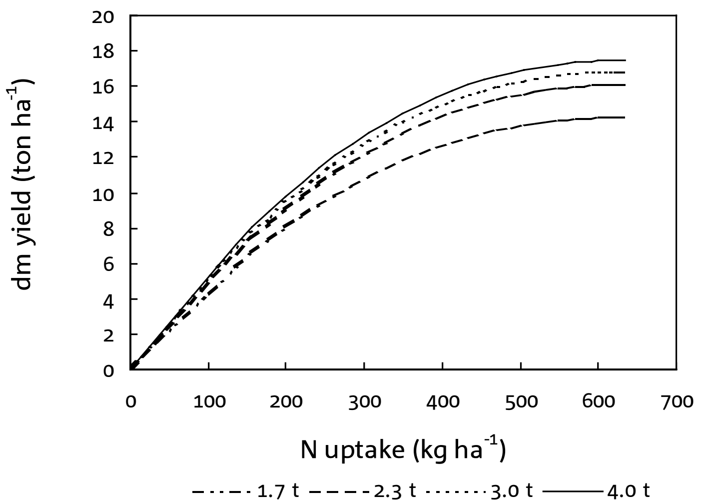

Figure 3.6. N uptake vs. dm yield at four harvesting frequencies for clay soils.

3.3.3 Stocking rates, herbage quality, animal feeding

Stocking rate is calculated from herbage yield and the herbage requirement per animal during summer. Hence, stocking rate is expressed per ha of grassland used for grazing in summer. This implies that at equal herbage yield, stocking rate under a day-and-night grazing regime is lower than under a day-grazing regime with 4.5 kg maize supplementation, where less herbage per cow is required.

The nutritional value of herbage is expressed in terms of energy and protein. The energy value of herbage is calculated using Dutch standards and expressed as Net Energy for Lactation (NEL, in kJ kg^{-1} dm), i.e. according to the Dutch VEM system (VEM is the unit for net energy for lactation in the Dutch feed evaluation system; 1 VEM = 6.9 kJ NEL; Anonymous, 1999a). The protein value is calculated according to the so-called DVE/OEB system (Tamminga *et al.*, 1994), based on the content of true protein digested in the small intestine (DVE, in kg kg^{-1} dm) and the degraded protein balance of the herbage (OEB, in kg kg^{-1} dm). See van de Ven (1996, 1992) and Anonymous (1999a) for details on calculation of nutritional values of herbage.

Energy and protein requirements are calculated for cows producing 5 000, 6 500 and 8 000 kg milk per year. The distribution of annual milk production over the year is based on cows calving in February. The year has been divided into five periods and energy and protein requirements are calculated for each of these periods separately (see van de Ven, 1996). It is assumed that feed intake capacity in the first period after calving (February to May) is too low to meet energy requirements and that cows have to mobilise body reserves that have to be restored again in the subsequent summer period. Hence, it has been assumed that at milk production levels of 5 000, 6 500 and 8 000 kg per cow per year, 2.5, 5.0 and 7.5% of the energy requirements in the first period after calving have to be supplied by body reserves and compensated again in the summer period. See van de Ven (1996) for calculation of energy and protein requirements of young stock.

3.3.4 Influence of grazing

The partitioning of dung and urine patches over the pasture is calculated according to a Poisson distribution (Peterson *et al.*, 1956; van de Ven, 1996), accounting for overlap of patches and assuming that faeces and urine are distributed at random. Calculated are the areas 'not covered', 'covered once' and 'covered twice' with either urine or faeces. Combinations of urine and faeces patches are calculated by multiplying the respective areas. The pasture is thus divided into nine parts covered less than three times with faeces or urine and a tenth part covered three times or more. For each of the ten field parts, the additional urinary and/or faecal N supply is calculated. Additional N from urine may lead to additional N uptake and herbage production. However, following van de Ven (1996) and based on van der Meer & Whitehead (1990) and Vertregt & Rutgers (1988) it is assumed that only 60% of urine-N is available for uptake by grass and 40% is either lost shortly after excretion or immobilised (see below). Moreover, urine-N is excreted throughout the grazing season, hence also in late summer and autumn when N uptake capacity of grass is low. Experimental results indicate that at maximum 30% of N excreted in urine during one grazing season can actually be taken up by herbage (van de Ven, 1996; van der Meer & Whitehead, 1990). Using these assumptions, 'applying' 100 kg available N from urine requires excretion of (100/60) = 165 kg urine-N, of which at maximum 50 kg N can be taken up. This uptake efficiency for urine-N can be compared with that from mineral fertiliser: assuming that ANR of fertiliser-N equals ρ_{ini} (86%), application of 100 kg N as mineral fertiliser to grassland results in 86 kg N extra N uptake. Hence, it can be argued that 'application' of urine-N, partly in unfavourable times of the growing season, reduces potential uptake to 50/86 = 60% of the corresponding uptake of fertiliser-N. Based on this reasoning, maximum uptake is set to 0.60*0.60 = 36% of total N voided in urine throughout the grazing season. Whether this maximum uptake is realised, depends on total available N level in the urine patch. Possible additional N uptake and herbage production in urine patches is calculated for each of the ten field parts separately, using the relationships in Figures 3.5 and 3.6, after which a weighed average per ha is calculated. The small effects of additional N from faeces on N uptake and herbage production (Deenen & Middelkoop, 1992) have been neglected.

3.3.5 Nitrogen losses

Ammonia (NH_3-N) volatilisation in grazing systems originates from decaying herbage and from faeces and urine excreted at pasture. Most important source is urine (Jarvis *et al.*, 1989a), because the main N component in urine is urea which has a high potential for NH_3-N volatilisation (Freney *et al.*, 1983). Given soil type and climate, NH_3-N losses from grazed swards therefore mainly depend on urine-N excretion at pasture. In turn, urine-N excretion is correlated to N application rate, because higher application rates lead to higher dietary N concentrations and increased excretion via urine (Jarvis *et al.*, 1989b), and because higher application rates are associated with higher stocking rates. Bussink (1992; 1994) measured NH_3-N losses from grazed swards on loam soils during the entire grazing periods of 1987, 1988 and 1990 and found a 'remarkable' consistency between total N excreted in dung and urine in the pasture and NH_3-N volatilisation. The fraction of N excreted at pasture and lost as NH_3-N was related to the average dietary N concentration:

vfrac = $2.717\ 10^{-7}\ ND^{3.389}$ ($R^2 = 0.96$) eq. 1

where,

ND = average dietary N concentration in summer (g N kg^{-1} dm);

vfrac = fraction of N excreted in dung and urine at pasture lost as NH_3-N (kg kg^{-1}).

Total NH_3-N volatilisation from grazed pastures can then be calculated as (Bussink, 1994):

V = vfrac*Nexcr eq. 2

where,

Nexcr = N excretion in dung and urine at pasture during one grazing season (kg N ha^{-1});

V = total NH_3-N volatilisation from a grazed pasture in the grazing season (kg N ha^{-1}).

To calculate total grazing-derived NH_3-N volatilisation in grazed grassland, equations 1 and 2 were implemented in GRASMOD.

NH_3-N volatilisation from faeces excreted at pasture is in the range from 3 (Ryden *et al.*, 1987) to 13% (van der Meer & Whitehead, 1990) of its N content. In GRASMOD it is assumed that 8% of N in faeces volatilises as NH_3-N. NH_3-N volatilisation from decaying grazing and harvesting losses is set to 3% of N contained in these losses (Vertregt & Rutgers, 1988). NH_3-N volatilisation from urine-N is calculated by subtracting NH_3-N emission from grazing and harvesting losses and faeces-derived NH_3-N volatilisation from total grazing-derived NH_3-N volatilisation as calculated with equations 1 and 2.

Based on an analysis of various experiments, Meeuwissen (CABO-DLO, unpublished data) derived a relationship between N application rate at cut-only grassland on clay soils and NO_3-N leaching from the rooted zone (Figure 3.7). This relationship is further used in this study. For cut-only grassland, NO_3-N leaching from the rooted zone is assumed constant and low (8 kg ha^{-1}) up to a N application level of 350 kg ha^{-1}. This assumption is in line with the observation of Prins (1983) that residual mineral N in clay soils at the end of the growing season reaches substantial values at N application rates exceeding 350 kg ha^{-1}. At low N application rates, the relationship in Figure 3.7 is also consistent with leaching measurements in three years under tile-drained cut-only grassland in a UK sandy loam overlying clay (Barraclough *et al.*, 1983): leaching in grassland given 250 kg N ha^{-1} was less than 7 kg NO_3-N in all years. At higher application rates, Barraclough *et al.* (1983) found lower leaching losses than in Figure 3.7. At 500 kg N ha^{-1}, leaching varied in the three years: 54, 19 and 8 kg N. Hence, in two out of three years, leaching was much lower than assumed here.

NO_3-N leaching in grazed grassland is calculated from NO_3-N leaching in cut-only grassland, correcting for additional N inputs via urine. In urine patches, N 'application' may be as high as 1 000 kg per ha. NO_3-N leaching associated with 'application' rates higher than 600 kg per ha are calculated by extrapolating the curve in Figure 3.7, i.e. assuming that 50% of additional N is leached. Above 'application' rates of 1 000 kg, it is assumed that all additional N is leached (van de Ven, 1996).

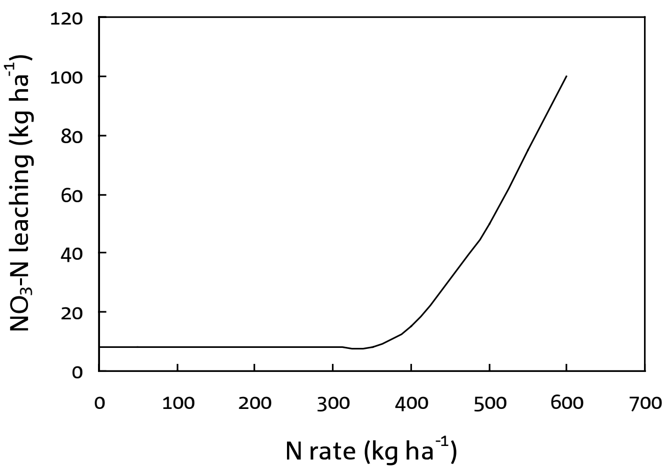

Figure 3.7. NO_3-N leaching below the rooted zone as a function of N application rate in cut-only grassland (Meeuwissen, CABO-DLO, unpublished data).

Part of N leached below the rooted zone eventually leaves the farming system as NO_3-N and part is denitrified to N_2 and N_2O in the subsoil. The fraction leached N that is denitrified in the subsoil is set to 25% (Boumans *et al.*, 1989) and 75% is assumed to emit as NO_3-N. These partitioning factors are close to those used by Scholefield *et al.* (1991) for grassland on loam and clay soils. The fraction of denitrification losses lost as N_2O is set to 8%.

De Klein & van Logtestijn (1994) quantified denitrification losses and N_2O-N emission from the top soil in urine patches on sandy soils in two two-weekly periods in early and late spring. In both periods, denitrification losses amounted to 18% of urine-N. N_2O losses were 16% of urine-N in the first period and 8% in the second period. N_2O could originate from both nitrification and denitrification. To estimate total N_2+N_2O losses from urine patches, the origin of N_2O should be known. If denitrification was the only source of N_2O, total N_2+N_2O losses would be 18% of applied urine-N. If nitrification was the only source of N_2O, total N_2+N_2O losses would range between 18+8=26 and 18+16=34% (de Klein & van Logtestijn, 1994). This range in total N_2+N_2O losses (18-34%) within 14 days after application is of the same magnitude as the proportion not accounted for in urinary N balance studies in which these losses have not been quantified (e.g. van der Meer & Whitehead, 1990; van der Meer, 1996; Williams & Haynes, 2000). Taking into account additional (unquantified) N_2+N_2O losses following the first two weeks, in GRASMOD, these losses are assumed to be in the upper half of the range reported by de Klein & van Logtestijn (1994) and set to 30% of excreted urinary N (after van der Meer, 1996). Moreover, in the experiments conducted by de Klein & van Logtestijn (1994), the fraction of urinary N lost as N_2O (8-16%) was very high compared to other estimates reported in the literature, e.g. Yamulki & Jarvis (1997; 0.68%), Allen *et al.* (1996; 0-2.3%), Velthof & Oenema (1997; 2.5%). Therefore, in GRASMOD it is assumed that only 2.5% of total N_2+N_2O losses is lost as N_2O. N_2O emission from faeces patches is set to 2.5% of excreted N (Velthof & Oenema, 1997).

3.3.6 Nitrogen balances

Combining all assumptions described above, results in N balances of dairy farming systems for the grazing period. The overall N balance of a dairy farming system with N application rate set to 400 kg N ha^{-1}, one cut used for silage making, cows in a day-and-night-grazing regime producing 6 500 kg milk per year at herbage supply level 1.0 is given in Table 3.14a, with underlying N balances for dairy cows (Table 3.14b) and grassland (Table 3.14c). All balance terms are expressed on a ha basis. Inputs of the overall balance are mineralisation, deposition, fertiliser and concentrates. Outputs are N contained in milk, meat and silage, volatilisation, leaching and denitrification losses, N excreted inside the stable in slurry and N incorporated in soil organic matter (SOM).

N intake by cows is 329 kg, 60 kg of which is incorporated in milk and meat (Table 3.14b). Total excretion in faeces and urine is 269 kg N, 224 of which is excreted at pasture. Mineralisation was calculated from the average N uptake in unfertilised objects of the N response experiments with grass (Table 3.13: 135 kg N ha^{-1}), corrected for N deposition. Assuming that (1) N uptake in unfertilised objects originates from N mineralised from organic matter and from deposition and (2) the recovery of this N equals ρ_{ini}, total N available from deposition and mineralisation can be calculated as 135/0.86 = 157 kg N. Further assuming that N deposition is 30 kg, of which 70% is available for uptake by grass (van de Ven, 1996), 136 kg N originated from N mineralised from organic matter. On average, 95% of the annually mineralised organic N is estimated to be available for uptake, hence total mineralisation is 143 kg N (Table 3.14c), of which 115 kg N is taken up by herbage. Of the 30 kg N from deposition, 18 kg is taken up by grass. From mineralisation and deposition combined, 6 kg is assumed to be lost by leaching and 2 kg by denitrification, hence 32 kg N is unaccounted for. Out of 400 kg N applied in mineral fertiliser, 336 kg is taken up by herbage, 5 kg is leached, 2 kg denitrified and 57 kg is not accounted for. Out of the 169 kg urine-N excreted during grazing, 32 kg is taken up, 32 kg lost by leaching, 62 kg lost via denitrification, 5 kg lost as NH_3-N and 39 kg unaccounted for. The major part of N excreted in faeces and that from grazing losses is incorporated in SOM. All N unaccounted for (Table 3.14c: 128 kg N) is from sources in which N was originally present in inorganic form. As this N did not contribute to any of the quantified losses, it either remains in the soil in inorganic form or it is immobilised in organic forms. Here it is assumed that it is immobilised in organic forms. Hence, total input to the soil organic N pool equals 128+128 = 256 kg N. With mineralisation amounting to 143 kg N, annual N accumulation is 113 kg N. Accumulation of organic N calculated in this way is not based on measurements but serves to close the N balance. The accumulation of organic N will in the longer term lead to increased mineralisation. The resulting overall balance of the dairy farming system is given in Table 3.14a.

Table 3.14a. *Overall balance of the dairy farming system. All data in kg N per ha per grazing season. Definition system characteristics: see text.*

Inputs		Outputs	
Mineralisation	143	Milk and meat	60
Deposition	30	Volatilisation	12
Fertiliser	400	Leaching	43
Concentrates	2	Denitrification	67
		Slurry	45
		Silage	93
		Incorporation in SOM	128
		Unaccounted for (immobilisation)	128
Total	575	Total	575

Table 3.14b. *N balance of dairy cows. All data in kg N per ha per grazing season. Definition system characteristics: see text.*

	Total	During grazing	Inside stable
Intake	329		
Retention in milk and meat	60		
Excretion in faeces	66	55	11
Excretion in urine	203	169	34

Table 3.14c. *N balance of grassland. All data in kg N per ha per grazing season. Definition system characteristics: see text.*

	Total	Uptake herbage	Volatilisation	Leaching	Denitrification	Incorporation in SOM	Unaccounted for
Mineralisation	143	115		6	2		32
Deposition	30	18					
Fertiliser	400	336		5	2		57
Urine	169	32	5	32	62		39
Faeces	55		4		1	49	
Grazing losses	82		2			79	
Total	879	501	12	43	67	128	128

3.3.7 Discussion

Grassland productivity

Deenen & Lantinga (1992) measured the effect of N application rate on herbage yield and N yield of cut and continuously grazed plots for a calcareous silty loam soil in three consecutive years. They expressed herbage yield in kVEM (1 kVEM = 6.9 MJ NEL). Measured yield under cutting was gross herbage yield, i.e. all herbage harvested by cutting at a height of 4-5 cm. Herbage yield and N yield in grazed plots were quantified by estimating herbage intake by dairy cows on the basis of animal performance data. Field measurements presented by Deenen & Lantinga (1992) can be compared to results from calculations with GRASMOD, combining routines on the effects of N application rate on dm yield and its NEL value, and effects of grazing. A cutting treatment was 'simulated' with GRASMOD by selecting zero-grazing (bb=1) as grazing system, hence with grass cut at 2 300 kg dm. Model results for the cutting treatment refer to gross kVEM yield, i.e. without subtracting harvesting and feeding losses. Continuous grazing was 'simulated' by choosing day-and-night-grazing as grazing system. To allow comparison with the grazing treatment in Deenen & Lantinga (1992), results from GRASMOD refer to kVEM intake and N intake by dairy cows. Field measurements and results of model calculations with GRASMOD are presented in a three quadrant diagram in Figure 3.8.

The relationship between N application rate and herbage yield is shown in quadrant II. This relationship depends on the proportion of applied N absorbed by the crop (N yield in the herbage, quadrant IV), and the effect of absorbed N on herbage yield (quadrant I). Figure 3.8, quadrant IV, shows for the cutting treatment that at each N input level, calculated N uptake is lower than N uptake as measured by Deenen & Lantinga (1992). The discrepancy between GRASMOD calculations and measurements increases with increasing N application rate. In fact, measurements show an almost linear response over the whole range of fertiliser applications (0-800 kg N). For the grazing treatment, calculations and measurements show better agreement. The effect of N yield on herbage yield (quadrant I) is 'simulated' reasonably well for the cutting treatment, however underestimating herbage yield at the extreme high N yields. Under grazing, the model overestimates herbage yield up to N yields of about 500 kg ha^{-1}, and underestimates herbage yields at higher N yields.

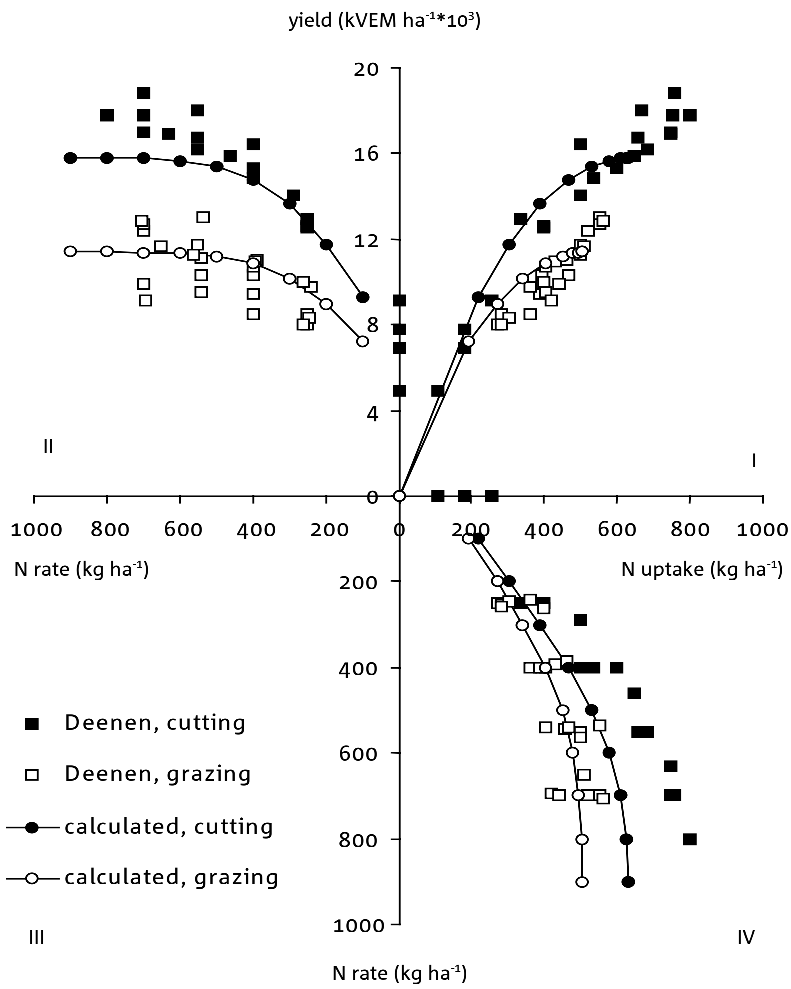

Figure 3.8. *The effect of N application rate on kVEM yield and N yield under a cutting regime and a continuous grazing regime, as measured by Deenen & Lantinga (1992) and calculated with GRASMOD.*

The major cause of the differences between calculations and measurements under cutting is the introduction of a ceiling to herbage dm yield and N yield in GRASMOD. This ceiling is defined by averages of parameters Y_{max} and α_{max} as estimated with QUADMOD on the basis of N response experiments (Table 3.13). The estimate for Y_{max} underestimates maximum herbage dm yield, hence herbage kVEM yield, for the location where Deenen & Lantinga (1992) carried out their experiments. As a consequence, both maximum herbage yield and maximum N yield (=α_{max}*Y_{max}: 636 kg N) under cutting are underestimated in GRASMOD. Underestimation of Y_{max}, however, does not explain under-estimation of N uptake at low N fertilisation. Underestimation of N uptake at low N levels points at underestimation of QUADMOD parameters S

(N uptake derived from indigenous soil-N, 135 kg N) or ρ_{ini} (initial ANR, 0.86). Both factors play a role. Deenen & Lantinga (1992) found an average indigenous soil-N uptake of about 155 kg N, i.e. 20 kg higher than in the N response experiments fitted to QUADMOD. They did not specify ANR values, but stated that these were high in all three years (>0.80). Judging from the figure in their paper, it seems that ANR values at low N rates were at least 0.88. They mention that ANR values exceeded 1.00 in three cases.

Relationships between N application rate, N yield and herbage yield under a grazing regime were calculated on the basis of these relationships under cutting, taking into account the specific effects of grazing. Compared to cutting, grazing has positive and negative effects on herbage yield (van der Meer, 1996; Deenen, 1994). A potentially positive effect is the return of N in excreta from grazing animals to the grass sward, increasing N supply. This may translate into higher N yield and herbage yield. Yields under grazing are negatively affected by a higher cutting frequency and by treading, poaching, fouling and urine scorching. Figure 3.8 shows that, both in the experiments and in calculations with GRASMOD, negative effects of grazing are dominant at all levels of N uptake.

As GRASMOD underestimates N uptake under cutting, the same would be expected under a grazing regime. However, this is not the case (see quadrant IV), indicating that negative effects of grazing on N uptake might be overestimated in the model. Quadrant I shows that at all levels of N uptake, herbage energy intake by dairy cows as estimated from animal performance data by Deenen & Lantinga (1992) is lower than that calculated in GRASMOD. Reasons behind this discrepancy are obscured by many uncertainties involved in quantifying herbage intake under grazing in both the experiments and in model calculations. It seems unlikely that differences between model calculations and measurements are due to the routines used in the model to calculate the energy content of herbage, because any systematic difference is absent in the cutting treatments.

Nitrogen leaching

Schils (1994) quantified NO_3-N leaching losses from tile drains under grazed pastures on a calcareous silty loam soil in three consecutive winters. N application rates varied among years and paddocks, but were in the range

200-360 kg per ha. Leaching losses were calculated as the product of weekly measured nitrate concentrations in drain effluent and estimated total drainage volume, the latter calculated from a hydrological mass balance. NO_3-N leaching varied among years and paddocks. Lowest measured leaching losses per winter period per paddock were about 5 kg NO_3-N ha^{-1}, and highest loads some 70 kg. The large majority of measured loads per year per paddock were in the range 10-30 kg ha^{-1}.

MacDuff *et al.* (1990) also measured NO_3-N leaching from tile-drained, continuously grazed pastures on a calcareous silty loam soil in three consecutive winters. Averaged over the experimental years, they measured N loads in drainwater amounting to 8, 29, 41 and 49 kg NO_3-N ha^{-1} under grassland fertilised with 250, 400, 550 and 700 kg N, respectively.

In a third experiment, Bronswijk *et al.* (1995) quantified NO_3-N leaching from a grazed pasture on a cracking heavy clay soil in two winters. In addition to leaching via tile drain effluent, leaching to the water-saturated zone was quantified. Total leaching losses in this study were much higher than in the experiments reported by Schils (1994) and MacDuff *et al.* (1990), amounting to 111 and 137 kg NO_3-N ha^{-1} under grassland fertilised with 523 and 437 kg N, respectively. These much higher leaching losses are attributed to a much shorter residence time of soil water in cracking clay soil, caused by fast transport of soil water to deeper layers via macropores and mesopores. Short residence time of soil water reduces the share of denitrification in total losses from agricultural soils.

Results of Schils (1994), MacDuff *et al.* (1990) and Bronswijk *et al.* (1995) are plotted in Figure 3.9, together with NO_3-N leaching losses as calculated with GRASMOD. Model calculations refer to a dairy farming system with cows in a day-and-night grazing system, producing 8 000 kg milk per year and, as in the study of Schils (1994), with two cuts used for conservation. Up to N application rates of 400 kg, calculated leaching losses are in agreement with measurements by MacDuff *et al.* (1990) and Schils (1994). Above that level, where quantification of leaching losses in the model is increasingly based on extrapolations, calculated losses increase more strongly than measurements by MacDuff *et al*. (1990) suggest, to reach levels as measured by Bronswijk *et al.* (1995).

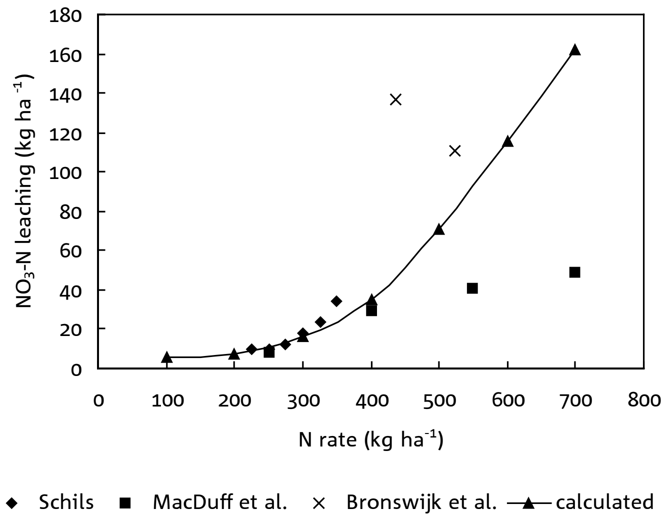

Figure 3.9. *Relationship between N rate and NO_3-N leaching losses for grazed grassland as calculated in GRASMOD and as reported by Schils (1994), MacDuff* et al. *(1990) and Bronswijk* et al. *(1995).*

Grazing-derived ammonia emission

Total grazing-derived NH_3-N emission is calculated on the basis of an equation derived by Bussink (1994), relating NH_3-N emission to dietary N concentration and the amount of N excreted at pasture. The equation used is based on field measurements on calcareous silty loam soil during three grazing seasons. Calculated NH_3-N emission as influenced by N application rate and these emissions as measured and calculated by Bussink (1994) in 1987, 1988 and 1990 are shown in Figure 3.10. Calculated NH_3-N emission is lower over the whole range of N application rates. Reason is that in the experiments of Bussink the number of cow grazing days per season was much higher. For example, at 550 kg N, the average number of cow grazing days was 957 in Bussink's experiments, whereas in GRASMOD it is 660, which is well in agreement with an average of 680 cow grazing days as measured over a period of three years by Deenen & Lantinga (1992). Less cow grazing days result in less N excretion at pasture, and therefore also in lower grazing-derived NH_3-N emission.

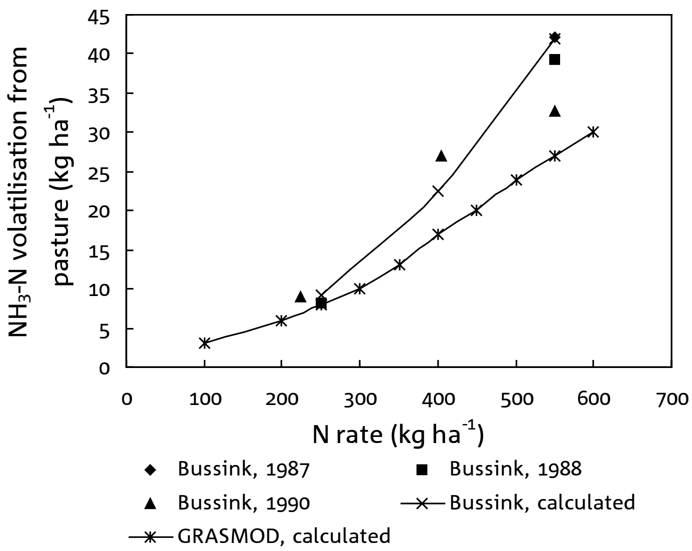

Figure 3.10. *The relationship between N rate and grazing-derived NH_3-N emission as measured and calculated by Bussink in 1987, 1988 and 1990 (Bussink, 1994) and as calculated with GRASMOD for dairy cows producing 8 000 kg milk in a day-and-night grazing system.*

3.4 Input-output coefficients of pig production activities

Characterisation of pig production activities covers growing pigs in housing system `jj` and feeding system `kk` (Table 3.15). Pigs can be housed in a conventional system (`jj`=1) or in a free-range system (`jj`=2). For both housing systems, pigs are assumed to enter the farm at an initial weight of 26 kg and leave the farm at a slaughter weight of 113 kg. Pigs in the conventional system are housed indoors on 50% slatted floors with a 0.7 m^2 area per pig. All excreted N is collected as slurry below the slatted floor. Pigs in the free-range system are housed in so-called Danish pens with a total area of 2 m^2 available for each pig, half of which is outdoors (after Huiskes *et al.*, 1999). One third of the indoor area has slatted floors. The outdoor area fully consists of slatted floors. Pigs in the free-range system are supplied with 10 kg wheat straw each. It is assumed that 75% of N excretion ends up in slurry and 25% in solid farmyard manure (Oenema *et al.*, 2000).

Table 3.15. Definition criteria and numerical values of the indices for production techniques for growing pigs

1. Housing system (definition criterion jj; maxjj=2)
jj= 1: conventional system
jj= 2: free-range system

2. Feeding system (definition criterion kk; maxkk=3)
kk= 1: 'standard' compound feeds and/or corn cob mix
kk= 2: combination of crushed wheat grains and compound feeds

In both feeding systems, pigs are fed *ad libitum*, according to a phase feeding system and using an automatic wet feeding installation. In the standard feeding system, feeding is with any combination of standard compound feeds and CCM, however CCM replacing 40% of the pigs' metabolisable energy (ME) requirements at maximum (van Ommeren, 1987; Arkes, 1984). In the second feeding system, pigs are fed a combination of crushed wheat and two supplementary compound feed types. Crushed wheat may at maximum substitute 25% of supplementary compound feed in phase 1 (on a fresh weight basis) and 50% in phases 2 and 3.
Input-output coefficients of pig production activities `XPIG(jj,kk)` (unit: pig places, i.e. unit in a pig stable where one pig can be housed) are quantified in the MGLP model (Chapter 4). Quantification is based on underlying technical coefficients, referring to energy requirements, amino acid requirements, P requirements and N and P excretion per pig. Values of these technical coefficients are given in Table 3.16. Daily weight gain is set to 791 g per pig per day for all four combinations of housing and feeding system (Anonymous, 1999b). ME requirement per pig was calculated from advised feed energy supply as determined by the physiological status of the pig (Anonymous, 1999b). For pigs in a conventional housing and feeding system these totalled 3 285 MJ ME, hence 37.76 MJ ME per kg weight gain. Due to higher energy requirement for maintenance, ME requirement per kg weight gain for free-range pigs was set 2.5 units higher than that for pigs in a conventional housing system (van der Peet-Schwering, Research Institute for Animal Husbandry, pers. comm.). Based on an experiment conducted by Scholten *et al.* (1997), ME requirement per kg weight gain for pigs fed crushed wheat was set 1.2 unit higher than in a conventional feeding system, the lower energy conversion efficiency being related to a lower digestibility of the energy contained in

crushed wheat. Effects of housing and feeding system on ME requirement per kg weight gain are summed.

Recommended levels of digestible lysine, digestible methionine+cystine and digestible P are given by Anonymous (1999b) and van der Peet-Schwering *et al.* (1999) and expressed in g per MJ ME. Total digestible lysine, methionine+cystine and P requirements per pig as applicable in this study (Table 3.15) were calculated by multiplication of total ME requirement and recommended levels of each nutrient per MJ ME.

N and P retention per pig is calculated as the difference between N and P contents of pigs at slaughter weight and these contents of pigs weighing 26 kg. N content of pigs weighing 26 kg is set to 24.0 g N per kg live weight (Coppoolse *et al.*, 1990). N content of pigs at slaughter weight is set to 24.5 g N per kg live weight (van der Peet-Schwering *et al.*, 1999). P content at initial and slaughter weight is calculated using an allometric function developed by Jongbloed & Everts (1992). N and P excretion in manure is calculated as the difference between intake and retention of these nutrients. In Table 3.16, as an illustration, N and P excretion data per pig are shown for the four combinations of housing and feeding system. Data for the two standard feeding systems (`kk`=1) refer to feeding compound feeds only and for the two systems with crushed wheat (`kk`=2) to systems in which the maximum amount of crushed wheat is incorporated in the diet, hence 25% in phase 1 and 50% in phases 2 and 3. Calculated N and P excretion for pigs in a conventional housing and standard feeding system agree with excretion data of commercial Dutch pig production units as presented by de Hoop (2002).

Table 3.16. Weight gain, energy and nutrient requirements, feed intake characteristics and nutrient excretion per pig in four combinations of two housing and two feeding systems.

Housing system / Feeding system:	Conventional /Standard jj=1, kk=1	Conventional /Crushed wheat jj=1, kk=2	Free-range /Standard jj=2, kk=1	Free-range /Crushed wheat jj=2, kk=2
Weight gain (g d^{-1})	791	791	791	791
Total ME requirement (MJ ME pig^{-1})	3285	3389	3504	3607
Digestible lysine requirement (g pig^{-1})	1731	1784	1847	1901
Digestible meth.+cyst. requirement (g pig^{-1})	1048	1080	1118	1150
Digestible P requirement (g pig^{-1})	498	514	532	547
Feed energy intake (MJ ME kg^{-1} weight gain)	37.76	38.95	40.27	41.46
Feed intake (MJ ME day^{-1})	29.85	30.80	31.84	32.78
Feed intake (kg kg^{-1} weight gain)	2.82	2.95	3.00	3.14
P excretion (kg pig^{-1})	0.74	0.99	0.82	1.08
N excretion (kg pig^{-1})	4.23	4.86	4.66	5.31

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CHAPTER 4

A multiple goal linear programming model for specialised and mixed farming systems

4.1 Introduction

The multiple goal linear programming (MGLP) model described in this chapter optimises the configuration of specialised and mixed farming systems. The model is formulated as an optimisation matrix, consisting of rows and columns. The rows in this matrix are linear mathematical equations representing objective functions and restrictions with respect to crop and animal production, cropping frequencies, crop sequences, supply of nutrients to crops, supply of energy and nutrients to animals, nutrient balances and labour requirements. The columns are the decision variables in these equations, representing crop production activities `XC(gg,e,r,p,n,qq)` (unit: ha), milk production activities `XG(yy,bb,nn,cc,mm)` (unit: ha), roughage production activities `XF(ff,nn)` (unit: ha), landless pig production activities `XPIG(jj,kk)`(unit: pig places), purchased production factors (e.g. seed, fertilisers, concentrates), sold products (e.g. crop products, pigs) and numerous intermediate variables required to fully formulate the problem (e.g. applying manure). An overview of indices and decision variables defined in the MGLP model is given in Appendices 5 and 6, respectively. Values of all decision variables are determined by optimisation, i.e. by solving the matrix for one of the defined objective functions. The solution is a set of values attached to the decision variables, describing a farming system with selected production activities, optimal for the considered objective. Each production activity is characterised by inputs and outputs, quantifying its unique contribution to the equations. Part of these inputs and outputs have been quantified in Chapter 3. Other ones are quantified in this chapter. In addition, the governing principles underlying the definition of decision variables, restrictions and objective variables are described.

4.2 Definition of specialised and mixed farming systems

This study has a regional scope. It considers the organisation and design of farming systems in an imaginary region located in the Dutch province Flevoland. Within the MGLP model, two types of regional organisation of farming systems are explicitly distinguished: farming systems in the context of specialised farming and farming systems in the context of mixed farming.

At the regional level, a farming system in the context of specialised farming (further referred to as a regionally specialised farming system) consists of a combination of a specialised dairy farming system (further referred to as the dairy sector[1]), a specialised arable cropping system (arable sector) and a specialised landless pig production system (pig sector). Any regionally specialised farming system has two key features, distinguishing it from regionally mixed farming systems. First, each of the three building blocks of a regionally specialised farming system functions as an independent economic unit. This implies that all internal transfers, i.e. transfers between the three agricultural sectors within the imaginary region of, e.g. feedstuffs and animal manures, are priced. Naturally, sales of e.g. milk, ware potatoes and pigs at slaughter weight to the outside market are also priced. Second key feature is that land use in the dairy sector is physically separated from land use in the arable sector. Land use in the dairy sector is a combination of permanent grassland and continuously cropped maize. Land use in the arable sector is an arable crop rotation with food crops and/or fodder crops. Direct allocation of land to the pig sector is not considered and therefore the pig sector is only indirectly land-based: land may serve as an outlet for pig manure and/or a source of feeds.

A regionally mixed farming system is defined by merging the economic units to form one new economic unit and by integrating land use of the dairy sector and the arable sector. Hence, in a regionally mixed farming system, all price tags attached to internal transfers are removed, and grassland and maize are incorporated into the arable crop rotation to form one new rotation. Hence, rotations in regionally mixed farming systems are characterised by a regular alternation between arable cropping and leys. The age at which leys in mixed farming systems are ploughed-in is fixed at 4 years.

The ratio of land allocated to dairy farming - permanent grassland and/or continuously cropped maize in specialised farming systems and temporary grassland in mixed farming systems - and land allocated to arable crops may vary (Table 4.1). Land use in regionally mixed farming systems by definition comprises temporary grassland and arable crops, combined in one rotation. Ploughing leys in that rotation at 4 years of age implies that each year 25% of the total grassland area is ploughed, after which one or more arable crops are

[1] In the remaining part of this chapter, the term 'sector' is only used in the context of specialised farming.

Table 4.1. Defined ratios of land allocated to dairy farming and land allocated to arable crops.

Land allocated to dairy farming (%)	Land allocated to arable cropping (%)
0	100
40	60
44	56
50	50
57	43
66	34
80	20
100	0

cultivated. The length of the arable phase may vary between 1 and 6 years. If the length of the arable phase is 1 year, the total length of the rotation is 5 years, with 4/5 (80%) of the total area under grassland and 1/5 (20%) under arable crops. Similarly, with a two-year arable phase, total rotation length is 6 years, with 4/6 (66%) grassland and 2/6 (34%) arable crops, etc. The ratios defined for mixed farming systems also define ratios used for specialised farming systems, so that a comparison between these two farming systems is less hampered by widely differing land use. Two additional ratios are defined, referring to specialised farming systems only: 100:0 and 0:100.

4.3 Boundaries

All available land should be used for milk production activities `XG(yy,bb,nn,cc,mm)`, roughage production activities `XF(ff,nn)` and/or crop production activities `XC(gg,e,r,p,n,qq)`. Export of cattle and pig manure to the outside world is not allowed, hence all manure produced should be applied within the region. Mineral fertilisers, concentrates and compound feeds can be purchased from the outside world. Feeds other than concentrates and compound feeds are available in quantities produced by their corresponding production activities.

4.4 Activities

4.4.1 Feeding animals

Some crop products may be consumed by animals via feeding activities. The feed ration of the dairy stock in the grazing season is calculated in GRASMOD (Chapter 3). The feed ration in winter may be composed of purchased concentrates and regionally produced conserved grass products, maize silage, whole crop cereal silage, fodder beets, corn-cob-mix (CCM) and wheat grains. Pig feeding activities refer to feeding purchased compound feeds and regionally produced CCM or crushed wheat grains.

4.4.2 Fertilising crops

N and P requirements of crops and grassland can be met by any combination of mineral fertiliser and/or pig manure and/or cattle manure. The term 'manure' denotes both slurry and solid farmyard manure. Solid farmyard manure is only produced in free range pig production systems. Cattle and pigs in conventional housing systems produce slurry. Slurry application to arable crops is in late summer or autumn. Slurry application after early-harvested crops (winter wheat, onion, green pea) can optionally be combined with Italian ryegrass as a catch crop. The catch crop is ploughed-in in November. Slurry application to arable crops is by injection. Slurry is applied to grassland in the growing season, either by injection or sod-fertilisation. Solid farmyard manure from free range pigs is applied in spring.

4.4.3 Purchasing inputs

Purchase activities refer to purchasing concentrates, compound feeds and mineral fertilisers against market prices. Costs of other purchased inputs are specified as variable costs, fixed costs and contract labour costs. Variable costs of crops cover costs of seed and planting material, pesticides, interest, and maintenance fertilisations (in € ha^{-1}), and costs related to conservation and/or storage of crop products (in € ton^{-1}). Variable costs of animals (in € $animal^{-1}$) cover costs of health management and, for pigs, costs of heating and electricity. Costs of land rent, buildings and machinery are accounted for in fixed costs. Fixed costs of buildings and machinery cover costs of depreciation, maintenance, insurance, interest and some additional costs (e.g. costs of storing machines). To exclude scale effects, fixed costs of machines are based on the concept of reimbursement in case of mutual usage of these machines, assigned to production activities according to their use, expressed in € ha^{-1}. Similarly, fixed costs of milking equipment, stables and manure storage have been assigned to dairy cows or pig places, hence are expressed in € per dairy cow or € per pig place. Contract labour is hired for application of manure, harvest of wheat, sowing of onions and sowing and harvest of sugar and fodder beet, maize silage, CCM and green pea. All costs are based on normative values (Anonymous, 1997a; Anonymous, 1997b; Anonymous, 1997c; Scholten *et al.*, 1997; Adams *et al.*, 1998). An overview of fixed costs, variable costs, contract labour costs and other costs is given in Appendix 7.

4.4.4 Revenues

Sale activities refer to selling milk, and culled calves and cows from the dairy farming system, pigs at slaughter weight from the pig production system and crop products from the arable cropping system. Producer prices used (Appendix 7) are averages covering the second half of the 1990s.

Additional revenues stem from direct area payments (definition criterion p; Section 3.2.1). Direct area payments were introduced in 1992 as part of the Mac Sharry reforms for various crops, including winter wheat, maize and green pea. Direct area payments served to compensate potential income loss as a result of reduced domestic price support within the European Union. If direct area payment is opted for, 10% of the area for which payment is requested has to be put under set-aside.

4.4.5 Labour requirements

Each activity requires labour inputs. Labour requirements for arable cropping, dairy farming and pig production activities on a 2-weekly basis were supplied by the Institute of Agricultural and Environmental Engineering (IMAG, Wageningen). The majority of coefficients describing labour requirements were expressed in hours per ha grassland or crops, taking into account all standard operations needed to cultivate a crop or manage grassland, and associated general tasks (administrative tasks, maintenance of buildings and machines, etc.). Labour requirements associated to keeping animals (milking, health management, feeding) were expressed in hours per cow, yearling, calf or pig.

4.5 Restrictions

4.5.1 Land use

The area assigned to a crop production activity `XC(gg,e,r,p,n,qq)` with cropping frequency `r` should be in agreement with that frequency. For instance, a 1:3 crop production activity in a specialised arable cropping system in which 60% of the available area is assigned to arable crops, should be cultivated at 60/3 = 20% of the available area. Similar constraint types ensure that (1) only feasible combinations of cropping frequencies can be combined in a rotation, (2) the appropriate `e` value is selected, given a crop and its preceding crop and (3) a 1:3 crop indeed returns to the same field after three years.

4.5.2 Feeding animals

Cattle feed rations should match energy requirements, while the DVE supply should at least cover the requirements. The structure value of the cattle ration should at least have a value of 1. Pigs' rations should match ME requirements and at least cover ileal digestible lysine, methionine+cystine and P requirements.

Based on their N content, nutritional values of regionally produced feeds were calculated using formulas in Anonymous (1998a). An overview of nutritional values of concentrates, compound feeds and regionally produced feeds is given in Appendix 7.

4.5.3 Nutrient balances and losses

Nitrogen

N balances and losses of all crop, milk and roughage production activities, as quantified in Chapter 3, referred to base situations, i.e. under the assumption that crops and grassland were fertilised with N in mineral form only. In the MGLP model, N fertilisation entirely in mineral form may be substituted by fertilisation with cattle and pig manure, which has implications for N balances and losses quantified in Chapter 3.

Cattle and/or pig slurry is applied to arable crops in late summer and autumn. Slurry application can optionally be combined with a catch crop Italian ryegrass if it is applied after early-harvested crops winter wheat, pea and onion. Slurry-N applied to arable crops is partitioned in effective, volatilised, leached, denitrified and organic N. Calculation of the partitioning factors is based on Beijer & Westhoek (1996), Lammers (1983) and Velthof *et al.* (1998). For each slurry-type, two sets of partitioning factors are used (Table 4.2). The first set applies only if slurry application is combined with a catch crop. It is valid in a lower domain of applied quantities, when the applied readily available mineral N can be fully taken up by the catch crop. The maximum slurry-N quantity that can be applied in the lower domain is limited by the maximum N uptake of the catch crop (set at 80 kg N ha^{-1}). Slurry-N application in excess of the maximum is allowed, but only if the lower domain is fully utilised. The additional slurry-N then is applied in an upper domain under validity of the second set, of which the readily available mineral N can not be taken up anymore by the catch crop. The second set also applies for slurry-N application without a catch crop. In mixed farming systems, slurry can also be applied in late summer and autumn in 4-years old ley, i.e. just before ploughing. This slurry-N is partitioned as if there were a catch crop. N in solid farmyard manure and slurry-N applied to grassland is partitioned over volatilised, effective and organic N, using standard values (Table 4.2; Beijer & Westhoek, 1996; Anonymous, 1997b, Anonymous, 1998b).

Organic N balances as quantified in Chapter 3 referred to separate crop, milk and roughage production activities, using mineral fertiliser only. In the MGLP model, organic N balances are calculated as the sum of organic N balances of the selected crop, milk and roughage production activities plus the amounts of organic N applied in manure. In specialised cropping systems, organic N balances are calculated separately for the areas assigned to permanent grassland, continuously cropped maize and the arable crop rotation. For mixed cropping systems, only one organic N balance is calculated, i.e. the organic N balance of the entire rotation. All organic N balances are constrained by an upper bound and a lower bound, to ensure that mineralisation levels as quantified in Chapter 3 are about maintained. Rather arbitrarily, upper and lower bounds are set to 1% of total organic N in the upper soil layer. Grassland contains 4 200-14 000 kg N ha^{-1} in organic matter in the top 20 cm (Vellinga *et al.*, 2000). Upper and lower bound for grassland are set to +100 and -100 kg N ha^{-1}, implying that the net change in organic N content should be in the range between +100 and -100 kg N ha^{-1}. Arable crop land contains about 5 000 kg organic N ha^{-1} (Vellinga *et al.*, 2000). Hence, upper and lower bound for arable cropping are set to +50 and -50 kg N ha^{-1}, respectively.

Table 4.2. Partitioning factors of N in cattle and pig slurry applied to arable crops below and above N uptake capacity of catch crop Italian ryegrass, and applied to grassland, expressed as a fraction of total-N applied.

	Cattle slurry	Pig slurry	Solid pig manure
Applied to arable crops below N uptake capacity catch crop (lower domain):			
volatilised N fraction	0.02	0.02	-
effective N fraction	0.39	0.43	-
leached N fraction	0.06	0.07	-
denitrified N fraction	0.08	0.09	-
accumulated N fraction	0.46	0.39	-
Applied to arable crops above N uptake capacity / without catch crop (upper domain):			
volatilised N fraction	0.02	0.02	0.12
effective N fraction	0.23	0.25	0.18
leached N fraction	0.29	0.33	-
denitrified N fraction	0.24	0.27	-
accumulated N fraction	0.24	0.14	0.70
Applied to grassland:			
volatilised N fraction	0.02	0.02	0.12
effective N fraction	0.50	0.53	0.18
accumulated N fraction	0.48	0.45	0.70

Typical for mixed farming systems is the regular alternation of leys and arable crops. The ley phase is associated with an increase in organic matter and the arable phase with a decrease (e.g. Haynes & Francis, 1990). In rotations characterised by a regular alternation of leys and arable crops, organic matter content under temporary leys will be lower than under permanent grassland, and organic matter content during the arable phase will be higher than under continuous cropping. These differences also apply with regard to the annual mineralisation of organic N.

Annual release of inorganic N under permanent grassland is fixed at 143 kg N ha^{-1} (Section 3.3.6), corresponding with about 1.6% of total organic N under permanent grassland. Annual release of inorganic N in continuous cropping is fixed at 120 kg N ha^{-1} (Section 3.2.2), corresponding with about 2.4% of total organic N under continuously cropped land. These percentages are used to quantify annual release of inorganic N during the ley and arable phase, respectively, when leys and arable crops alternate. Total organic N under such rotations is calculated as the weighted average of organic N under permanent grassland and organic N under continuous cropping, as determined by the - fixed - length of the grassland phase and the - variable - length of the arable phase. Results of the calculations are summarised in Table 4.3. The approach followed neglects temporal variation in inorganic N release in the course of the rotation.

Input-output coefficients for crop, milk and roughage production activities as quantified in Chapter 3 apply to specialised farming systems. Input-output coefficients of activities eligible for adoption in mixed farming systems are newly generated, using mineralisation parameters from Table 4.3, keeping all other parameters as they were. Consequently, input-output coefficients for mixed farming systems are different for each defined rotation length.

NH_3-N volatilisation as quantified in Chapter 3 included volatilisation from excreted faeces and urine during cattle grazing and from decaying herbage. Additional volatilisation follows application of manure (Table 4.2) and originates from cattle and pig stables and manure storages.

NH_3-N volatilisation from stables and manure storages for dairy cows in zero-grazing systems was set to 15.4% of N excretion in summer and to 11.4% of N excretion in winter (Oenema *et al.*, 2000). For young stock in zero-grazing systems, these values are set to 13.9 and 10.3%, respectively (Oenema *et al.*, 2000). For low-emission systems, the emission percentages were halved.

Table 4.3. Annual release of inorganic N under continuous cropping, under permanent grassland and under regular alternation of leys and arable crops as a function of the length of the arable phase.

grassland phase (years)	arable phase (years)	total organic N (kg N ha^{-1})	annual release under grassland (kg N ha^{-1})	annual release under arable crops (kg N ha^{-1})
permanent grassland		9000	143	-
continuous cropping		5000	-	120
4	1	8200	130	197
4	2	7666	122	184
4	3	7286	116	175
4	4	7000	111	168
4	5	6778	108	163
4	6	6600	105	158

Although N excretion inside the stable is lower when animals graze part of the day, the emitting area is equal to that in zero-grazing systems. Hence, compared to zero-grazing systems, the emitting area per kg N excreted inside is much larger when cows are grazing, hence the relationship between the amount of N excreted in summer inside the stable and NH_3-N emission is not linear. To account for this effect, model calculations of Smits *et al.* (1998) were used, who found that stable-derived NH_3-N emission for cows in a day-and-night and day-grazing system, fed the same fresh grass-based diets, amounted to 29 and 80% of that for cows in a zero-grazing system. Hence, NH_3-N emission for day-and-night grazing and day-grazing dairy cows is set to 4.5 and 12.3% of N excretion in summer.

NH_3-N volatilisation from pigs in a conventional housing system is set to 20% of excreted N (van der Peet-Schwering *et al.*, 1996; Aarnink *et al.*, 1996). For pigs in a low-emission conventional housing system, this percentage is reduced by 60% (van den Brok *et al.*, 1997). NH_3-N emission from free-range housing systems for growing pigs has never been measured in the Netherlands. Compared to conventional housing systems, in free-range systems, both conditions promoting (higher air velocities, larger emitting area) and reducing (lower temperature, use of straw for bedding) NH_3 emission are present. The combined effect of these conditions is unknown. Therefore, it is assumed that NH_3-N emission in the free-range system equals that of the conventional housing system, i.e. 20% of excreted N.

Phosphorus

To maintain P-status of soils, P-removal with crop and grass products should be at least compensated by P-inputs. In specialised farming systems, this constraint applies to each of the - physically separated - units, arable crop rotation, permanent grassland and continuously cropped maize. In mixed farming systems, the constraint applies to the entire - physically integrated - crop rotation. P-inputs can be mineral fertiliser and/or regionally produced animal manure. Manure-P input is calculated from manure-N input, assuming fixed and slurry-type-specific N/P ratios, calculable from data presented in Chapter 3. The resulting N/P ratios only slightly differ from these given by Beijer & Westhoek (1996).

4.6 Objectives

Frequently used objective functions in the chapters to follow include:

- regional NO_3-N leaching (restricted/minimised) (kg NO_3-N ha^{-1} yr^{-1})
- regional NH_3-N volatilisation (restricted/minimised) (kg NH_3-N ha^{-1} yr^{-1})
- sectoral NO_3-N leaching (restricted/minimised) (kg NO_3-N ha^{-1} yr^{-1})
- sectoral NH_3-N volatilisation (restricted/minimised) (kg NH_3-N ha^{-1} yr^{-1})
- regional labour income (maximised) (€ ha^{-1} yr^{-1})
- sectoral labour income (maximised) (€ ha^{-1} yr^{-1})

Regional NO_3-N and NH_3-N losses pertain to an average ha of the selected regional farming system. Sectoral N-losses pertain to N-losses in those parts of the region assigned to the dairy sector and arable plus pig sector, respectively, as part of regionally specialised farming systems. Only if the entire region is assigned to just one sector, regional N-losses equal sectoral N-losses. Labour income is calculated as financial returns from sold products and EU direct payments minus fixed costs, variable costs and contract labour costs. It covers the remuneration for the use of the production factor labour. Labour income can be maximised for individual agricultural sectors - as part of regionally specialised farming systems - or for the entire region. Maximisation of regional labour income in specialised farming systems implies maximisation of the sum of labour incomes in the dairy, arable and pig sectors. Maximisation of regional labour income in mixed farming systems implies maximisation of labour income from agricultural activities eligible for adoption in mixed farming systems.

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CHAPTER 5

Nitrogen emissions in specialised and mixed farming systems under Dutch manure policy regulations

5.1 Introduction

Dutch agriculture contributes considerably to emissions of N and P to air, groundwater and surface waters. These emissions negatively affect natural ecosystems and drinking water quality. To reduce emissions from agriculture, legislation has been introduced since the mid-1980s. Dutch manure policy for the near future evolves around two interrelated systems: the MINeral Accounting System (MINAS) and the manure contract system (van den Brandt & Smit, 1998; Henkens & van Keulen, 2001). MINAS is a policy instrument to restrict nutrient emissions from farms to the external environment. For the MINAS system to function properly and to prevent large scale fraud, a prerequisite is that total manure production is in balance with manure application opportunities. The manure contract system is the policy instrument through which this balance is achieved. The core of the system is that it couples manure production at farm scale with application opportunities within that farm or at other farms. With introduction of MINAS and the manure contract system in Dutch agriculture, the government intends to attain objectives of the EU Nitrate Directive and the EU Drinking Water Directive.
To reduce ammonia (NH_3) emission from agriculture, a proposal for new legislation has recently (June 2001) been submitted to Dutch Parliament. Implementation of this legislation should reduce the area of nature reserves in which critical loads of potential acidity and N are exceeded.

5.1.1 MINAS

MINAS essentially is based on a farm gate nutrient (nitrogen (N) and phosphorus (P)) balance in which nutrient surplus is calculated as total inputs minus total outputs. If this surplus exceeds a threshold value, the farmer has to pay a levy proportional to the excess. MINAS was first introduced in 1998 on intensive livestock farms, but applies to all agricultural holdings from the year 2002. Hence, from 2002 onwards, each agricultural holding is obliged to monitor N and P flows entering the farm in animals, feeds, mineral fertilisers and animal manures and leaving the farm in animals and/or their products, crops and animal manures. An overview of default values for nutrient flows and contents for clay soils, as used in the MINAS system from 2003 onwards, is given in Table 5.1. Nutrients leaving the farm in arable crops intended for human

Table 5.1. *Default values used in the MINAS system and the manure contract system as of 2003 for clay soils.*

	N	P
MINAS		
Nutrient output arable crops for human consumption (kg ha^{-1})	165	28
Nutrient contents fodder crops (g kg^{-1} dm)		
feed grain	22.4	4.0
silage maize	14.3	2.0
Corn-Cob-Mix	17.0	3.4
wheat straw	6.7	0.9
fodder beet	13.1	1.5
Nutrient contents animals (kg per animal)		
dairy cow	15.2	4.4
calf	1.3	0.3
yearling	12.3	3.5
piglet	0.6	0.1
pig at slaughter weight	2.6	0.6
'Unavoidable' N-loss per animal (kg per animal per year)		
dairy cow	30.0	-
calf	9.7	-
yearling	20.5	-
pig (conventional housing)	4.1	-
pig (free range system)	8.6	-
Levy-free surpluses (kg per ha^{-1})		
grassland	180	8.7
arable land	100	8.7
Manure contract system		
N excretion per animal (kg per animal per year)		
dairy cow	107	
calf	36	
yearling	74	
pig	8	

consumption are set to 165 kg N and 28 kg P ha^{-1}. For fodder crops (maize, wheat, grass and fodder beet), default nutrient contents are used, that, multiplied with actual quantities sold, yield total nutrients leaving the farm. Default nutrient contents are also used for animals leaving the farm. In MINAS, part of the N-losses associated with animal production are considered 'unavoidable', and the farmer is allowed to add part of the unavoidable losses to N output. Total 'unavoidable' N-loss is calculated as the number of animals present multiplied with a default value for 'unavoidable' N-loss per animal category per year. Per hectare grassland at the farm, the first 60 kg N of the 'unavoidable' losses can not be added to the output. Hence, total 'unavoidable' N-loss is reduced by 60*grassland area, and if the resulting value exceeds 0, the farmer is allowed to add that value to N output.
MINAS nutrient surpluses are calculated as total inputs (excluding deposition, N fixed in grass-clover mixtures and P in mineral fertiliser) minus total outputs (including 'unavoidable' N-loss). The threshold values for N and P are calculated on the basis of levy-free surpluses set by the government. The levy-free N surplus is differentiated according to soil type and land use and gradually tightened over time. For clay soils from 2003 onwards, it amounts to 180 kg N ha^{-1} grassland and 100 kg N ha^{-1} arable land. The levy-free P surplus is set to 9 kg ha^{-1}, irrespective of soil type and land use. The levy for N is set to € 2.30 per kg excess. The P levy is set to € 3.93 for each kg exceeding the threshold.

5.1.2 Manure contract system

EU Council Directive 91/676/EEC, issued 12 December 1991, better known as the Nitrate Directive, has the objective to reduce water pollution caused or induced by nitrates from agricultural sources, and to prevent any further such pollution. 'Water' includes both groundwaters and surface waters. An important feature of the Nitrate Directive is that it specifies the maximum amount of animal manure that can be applied to farmland each year. By the year 2003, this amount for each farm should not exceed 170 kg N per ha, including N excreted by grazing animals. A derogation may be approved for crops with a long growing season and a large capacity for N uptake and for conditions conducive to high denitrification rates. Such derogation for grassland has been requested by the Dutch government (Willems *et al.*, 2000). The Dutch government is of the opinion that, because of the long growing season of grass, the maximum dose of N in animal manure applied to grassland can be increased from 170 to 250 kg ha^{-1}, without jeopardising objectives of the Nitrate Directive. The Dutch derogation request is still under consideration with the European Commission, but unless stated otherwise, in the remaining part of this chapter it is assumed that the request will be granted.

Implementation of Nitrate Directive regulations in the Netherlands is regulated through the so-called manure contract system. In this system, manure production at livestock farms is calculated in a standardised way by multiplication of default values for annual N excretion per animal (Table 5.1) with the number of animals present at the farm. The result of this multiplication is further referred to as 'standardised manure production'. Currently, the balance at national scale between production and 'consumption' of animal manures is such that arable farmers are paid by livestock farmers if they use manures to fertilise their crops. Livestock farms producing manure in excess of 170 kg N per ha arable land plus 250 kg per ha grassland are obliged to conclude contracts with 'consumers', e.g. arable farmers or processing industries, and to formally transfer the excess to arable farmers or other 'consumers'. Current Dutch manure policy permits livestock farms to deviate from this regulation, by allowing farms to produce and apply manure in excess of the stipulated rates, provided their MINAS surpluses do not exceed levy-free surpluses. Such livestock farms conclude 'manure contracts on paper' with 'consumers', but are not obliged to actually transfer the excess manure to the 'consumer' and thus save manure disposal costs. If either the MINAS N surplus or the MINAS P surplus exceeds the levy-free surplus, actual transfer is obliged. The manure contract system thus serves as a stimulus for livestock farmers to realise MINAS surpluses below the levy-free surpluses. Arable farmers are allowed to conclude manure contracts for 170 kg manure-N per ha arable land at maximum.

The consequence of the Dutch translation of Nitrate Directive regulations is that standardised manure production *at national scale* does not exceed 170 kg N per ha arable land plus 250 kg per ha grassland, but this is not necessarily so at *farm scale*. Strictly speaking, the Dutch interpretation is not in accordance with the 170/250-regulation in the Nitrate Directive, which is formulated at farm scale. In the remaining part of this thesis, this Dutch interpretation of the Nitrate Directive is denoted the 'flexible interpretation' of the Nitrate Directive, as opposed to the EU's strict, farm scale interpretation. It is currently not known whether the flexible interpretation by the Dutch government will be accepted by the European Commission.

5.1.3 Ammonia

Policy objectives with respect to NH_3 emission are set in the Fourth National Environmental Policy Plan (Anonymous, 2001a). By the year 2010, total NH_3 emission in the Netherlands should not exceed 100 kton (82 kton NH_3-N). In the longer term (2030), NH_3 emission should be reduced to 30-55 kton. The goal for the year 2010 has been translated into targets for different sectors of the economy contributing to NH_3 emission. Target for the agricultural sector is to reduce NH_3 emission in the year 2010 to 86 kton. This value may be compared with NH_3 emission from agriculture in 1999, amounting to 164 kton (Anonymous, 2001b). The 86 kton target for the agricultural sector at national scale corresponds to a target of 2.1 kton for the province Flevoland (Anonymous, 2001a). With a total area under grassland, arable crops and outdoor horticulture of about 91 000 ha, total NH_3 emission per ha should not exceed 23 kg NH_3 (19 kg NH_3-N) to meet the 2010 target.
To attain the policy objectives for NH_3, a proposal for new legislation has been submitted to Dutch Parliament (Anonymous, 2001c). Proposed legislation consists of a general emission policy, applicable to the whole country, and additional, more restrictive policies for specific areas, designated as vulnerable areas. The general emission policy sets limits to the maximum permitted NH_3 emission from stables and manure storages. Implementation is by setting specific requirements, laid down by law, to newly built stables or renovated stables with respect to NH_3 emission per animal place, applying the ALARA (=As Low As Reasonably Achievable) principle. In 2008/2010 all stables should meet these requirements. Additional policies for vulnerable areas aim at preventing an increase in NH_3 emission in these areas. They constitute a ban on establishment of new livestock farms and definition of local ceilings to NH_3 emissions.

5.1.4 Problem definition

The MINAS and the manure contract system should enable Dutch agriculture to attain the following two objectives (Oenema *et al.*, 1998): (1) NO_3 concentration in the shallow groundwater of agricultural land is less than 50 mg per litre (11.3 mg NO_3-N per litre), and (2) mean N emission from agriculture to surface waters has decreased by more than 50%, with 1985 as reference year. In north-western Europe, the precipitation surplus in winter is about 300 mm. If all of this surplus adds to recharge of groundwater, the 50 mg norm implies that NO_3-N leaching should not exceed 34 kg ha^{-1}. If, on the other hand, surplus water moves only horizontally (through surface run-off, macropores or tile drains), not more than 7 kg N ha^{-1} should be discharged in surface waters to attain the target value of 2.2 mg N per litre for stagnant surface waters. In practice, the relation between NO_3-N leaching from agricultural soils and N concentration in ground- and surface waters is much more complicated. The issue is subject to much debate (e.g. on definitions of 'groundwater suitable for drinking water' and 'stagnant surface waters') and is afflicted with large uncertainties (e.g. of denitrification rates during the time span between drain discharge into a ditch and transport to a stagnant surface water body). In this study, "complying with the objectives specified in the Nitrate Directive" is simplified to "reducing NO_3-N loss to a value below 34 kg ha^{-1}".

Whether target values for drinking and surface waters can be realised depends on the efficacy of MINAS and the manure contract system in preventing farmers from engaging in activities that lead to high leaching losses. This efficacy is determined by such aspects as the relationship between MINAS N and P surpluses and potential groundwater charge, the magnitude of the levy-free surpluses and the values of the levies. Schröder & Corré (2000) criticise the methodology applied to calculate MINAS surpluses, arguing that these surpluses are generally much lower than actual, agronomic surpluses, and hence less suitable indicators of environmental pollution. Underestimation of surpluses in the MINAS system is caused by underestimation of inputs (due to exclusion of nutrients in deposition, N fixed in grass-clover mixtures and P in mineral fertiliser) and overestimation of outputs (due to high default values used to quantify nutrient removal in arable crops and 'unavoidable' N-losses; Table 5.1). In addition, Schröder & Corré (2000) point out that nutrient surpluses in general are not always appropriate indicators of environmental pollution, e.g. when soils act as nutrient sinks or sources. Dekker & van

Leeuwen (1998) suggest that economic considerations rather than environmental goals played an important role in the decision-making process on definition of the levy-free surpluses.

In this chapter, nitrogen emissions in regionally specialised and mixed farming systems under Dutch manure policy regulations are investigated, using the multiple goal linear programming (MGLP) model described in Chapters 3 and 4. Simultaneously, the efficacy of MINAS and the manure contract system in reducing undesirable nitrogen emissions can be evaluated. Research questions are:

(1) what is, from the perspective of maximum labour income, the optimal configuration of specialised and mixed farming systems under current design of MINAS and the manure contract system and how can possible differences in performance of specialised and mixed farming systems be explained?

(2) how large are NO_3-N and NH_3-N emissions in specialised and mixed farming systems under current design of MINAS and the manure contract system?

(3) which measures are taken by the model to meet the standards of the EU Nitrate Directive and to meet NH_3-N policy objectives?

As outlined above, it is assumed here that policy objectives with respect to N emission reductions are attained if NO_3-N leaching is below 34 kg ha^{-1} and NH_3-N volatilisation below 19 kg N ha^{-1}. These two target values, derived from policy objectives at national scale, are further referred to as policy *standards*.

5.2 Methodology

5.2.1 Implementation of policy regulations in the model

For specialised farming systems, MINAS N and P surpluses are calculated separately for each economic unit represented in the farming system, i.e. the arable sector, dairy sector and landless pig sector[1]. In line with policy proposals, the dairy sector is allowed to produce and apply manure-N to its land in excess of the Nitrate Directive regulations, provided its MINAS surpluses do not exceed

[1] In the remaining part of this chapter, the term 'sector' is only used in the context of specialised farming.

levy-free surpluses. If either the MINAS N or the MINAS P surplus exceeds the levy-free surplus, standardised manure-N production within the dairy sector is limited to 170 kg per ha maize plus 250 kg per ha grassland, increased with the quantity of cattle manure that is exported to the arable sector. The maximum amount of cattle and pig manure that can legally be applied in the arable sector is 170 kg N per ha, irrespective of its MINAS surpluses. A recent survey, however, indicates that arable farmers have a reserved attitude towards concluding manure contracts that would force them to apply the maximum permitted amount of manure-N at their farm (Hees & Hin, 2000). Main reasons for this reserved attitude are (1) the coercive nature of the manure contract system, (2) the perceived risk of having to pay MINAS levies and (3) the absence of contacts with livestock farmers. Based on the results of this survey and unless stated otherwise, it is assumed that arable farmers conclude manure contracts for only half the maximum amount permitted, i.e. 85 kg N ha^{-1}. In other words, the rate of acceptance of manure by arable farmers is set to 50%.

For mixed farming systems, where the arable, dairy and pig sectors are merged to form one economic unit, MINAS surpluses are calculated for the farming system as a whole. If MINAS surpluses exceed levy-free surpluses, standardised manure production is limited to 170 kg N per ha arable land and 250 kg N per ha grassland. More manure-N can be produced and applied within mixed farming systems, if this is combined with MINAS surpluses below levy-free surpluses.

5.2.2 Maximum sectoral labour incomes without and with restrictions on N-losses

In a first optimisation cycle, labour income is maximised for each of the three sectors, dairy farming, arable cropping and pig production separately, without restrictions on N-losses. This results in three optimum specialised farming systems. If, for example, labour income is maximised for the dairy sector, logically, all available land will be assigned to that sector. Moreover, pig production will not be selected, because that would claim part of the limited manure application opportunities within the region, at the expense of labour income in the dairy sector. Determination of maximum labour income in each sector involves two optimisations. When, for example, maximising labour income in the arable sector, maximum labour income in that sector is calculated in the first optimisation. In the second optimisation, regional labour income, i.e. the sum of labour incomes in the arable, pig and dairy sector, is maximised, with maximum labour income in the arable sector from the first optimisation serving as a restriction. Hence, the second optimisation yields the configuration of a farming system realising maximum regional labour income at maximum labour income in the arable sector. To calculate maximum sectoral labour incomes for the pig and dairy sector, the equivalent procedures are followed.

In a second optimisation cycle, labour income is maximised for each agricultural sector with restrictions on N-losses. Maximum NO_3-N leaching is restricted to 34 kg ha^{-1} and maximum NH_3-N volatilisation to 19 kg ha^{-1}. Further set-up of calculations is as under maximum sectoral labour incomes without restrictions on N-losses.

Configurations of specialised farming systems realising maximum labour income, without and with restrictions on N-losses, will be discussed, including associated agronomic and MINAS nutrient balances.

5.2.3 Establishment of solution area

In a third optimisation cycle, each of the goals, regional labour income, NO_3-N leaching and NH_3-N volatilisation is optimised individually, separately for the regionally specialised and the regionally mixed farming system. This results in the best attainable value for each goal under the defined conditions. In a fourth series of optimisations, regional labour income is maximised, while gradually tightening restrictions on maximum permitted NO_3-N leaching and maximum permitted NH_3-N emission. Through this procedure, the so-called solution area, as defined by the extreme values of the goals regional labour income, NO_3-N leaching and NH_3-N emission is established. Solution areas are established separately for the specialised farming system and the mixed farming system. Each solution area is presented as a contour plot, with each co-ordinate (`x,y,z`) representing an optimal set of the three goals. In line with agri-environmental policies, restrictions on maximum permitted N-losses are imposed on the economic units constituting the farming system. Hence, for specialised farming systems restrictions are imposed on each of the three economic units arable sector, pig sector and dairy sector. Restrictions for mixed farming systems are set at the scale of the entire farming system, corresponding with the entire region. Note that both approaches fundamentally differ. In mixed farming systems, high N-losses in one part of the region (e.g. those occurring in arable crop production) can be compensated by low N-losses in another part of the region (e.g. those occurring in milk production). In specialised farming systems, such a compensation is not possible, as restrictions are set to those parts of the region assigned to the arable, pig and dairy sector, respectively. Setting restrictions at sector scale, strongly reduces the 'degrees of freedom' available to the MGLP model.

5.2.4 Evaluation of manure policy regulations

Results of all optimisations are configurations of regionally specialised or mixed farming systems, each with an optimal set of the three goal variables regional labour income, NO_3-N leaching and NH_3-N emission. Because all optimal farming systems comply with Dutch manure policy regulations, optimisation results can be used to evaluate the efficacy of these regulations in avoiding excess nutrient emissions. Therefore, the configuration of the regionally specialised farming system and the regionally mixed farming system under maximum labour income, hence without restrictions on NO_3-N leaching and NH_3-N emission, will be shortly discussed, including associated N-losses and MINAS N and P surpluses. Subsequently, the configurations of the specialised and mixed farming systems complying with policy standards (NO_3-N leaching < 34 kg ha^{-1}; NH_3-N emission < 19 kg ha^{-1}) are discussed. Measures taken to attain the policy standards are examined by comparing the configurations of farming systems without and with restrictions on N-losses.

5.3 Results

5.3.1 Configuration of the arable, pig and dairy sector without and with restrictions on N-losses

Arable sector

Without restrictions on N-losses, maximum labour income in the arable sector is € 926 ha^{-1} (Table 5.2). All land is used for arable crops, which is combined with conventional pig production. Maximum regional labour income at maximum income in the arable sector is € 1 006 ha^{-1}, as labour income in the pig sector is € 80 ha^{-1}. NO_3-N loss is 58 kg ha^{-1} and NH_3-N loss 30. Maximum labour income in the arable sector is attained with a 1:4 crop rotation with winter wheat, ware potato, onion and sugar beet, cultivated at economically optimal yields and applying the maximum permitted amount of manure-N (85 kg ha^{-1}; Table 5.2). Winter wheat is used as feed grain in the pig sector. Other crop products are sold to the external market. There are 7.2 conventional pig places per ha of land in the region. Pig slurry is applied after winter wheat and onions and is combined with a catch crop, contributing to N supply of sugar beet and ware potato, respectively. The quantity of pig slurry applied after winter wheat (260 kg total-N ha^{-1}) is such, that only a small proportion of readily available mineral N in the slurry can be taken up by the catch crop. The remainder is subject to leaching in winter. The quantity of pig slurry applied after onions is smaller (83 kg total-N ha^{-1}) and all readily available mineral N can be taken up by the catch crop. Averaged over the crop rotation, annual total-N input in mineral fertiliser and pig slurry is 193 kg ha^{-1}, of which 136 kg is effective.

The optimal design of the crop rotation from the perspective of labour income represents a compromise between allocating an area as large as possible to the profitable crops ware potato and sugar beet, avoiding yield reductions due to high cropping frequencies and avoiding yield reductions to unfavourable crop sequences. The result is, that a 12% yield reduction is accepted for ware potato due to cropping frequency and a 16% yield reduction for sugar beet due to cropping frequency and crop sequence (see Chapter 3). Note that yield reduction in sugar beet due to crop sequence is unavoidable, as all preceding crops available for selection lead to yield reductions (Table 3.7). The selected crop preceding sugar beet under maximum income in the arable sector is winter wheat, which results in the smallest yield reduction (5%; Table 3.7). Yield reductions due to high cropping frequencies could have been avoided, if cropping frequencies of ware potato and sugar beet would be reduced to 1:6 and 1:7, respectively. Trade-off is smaller areas allocated to these crops, which, from the perspective of maximum income in the arable sector apparently is unattractive.

More profitable free range pig production is not selected, because it increases contract labour costs for manure application in the arable sector. In free range pig production, part of manure produced is in solid form, of which application costs are higher than for slurry (see Appendix 7). Hence, maximum labour income in the arable sector can only be attained if the maximum permitted amount of manure-N is applied as slurry.

Table 5.3 shows agronomic and MINAS nutrient balances for the arable and the pig sectors. Agronomic surpluses in the arable sector are 79 kg N and 1 kg P ha^{-1}, and MINAS surpluses are 14 kg N and -9 kg P ha^{-1}. MINAS surpluses are lower than levy-free surpluses, hence no levies are paid in the arable sector.

The only loss term in the agronomic balance of the pig sector is NH_3-N emission from pig stables, amounting to 20 kg N ha^{-1} (Table 5.3). MINAS N surplus in the pig sector is -8 kg ha^{-1}. The difference between agronomic and MINAS N surplus is mainly caused by the difference between the default 'unavoidable' NH_3-N loss term used in the MINAS system (Table 5.1: 4.1 kg NH_3-N per pig place) and the NH_3-N loss according to assumptions in the MGLP model (2.8 kg NH_3-N per pig place). Both, the agronomic P surplus and the MINAS P surplus have small negative values. This runs counter to the intuition that all P inputs in the landless pig sector should be accounted for in outputs, and hence both the agronomic and MINAS P surplus should be zero. Slightly negative P surpluses show that P outputs are overestimated and 1 kg 'virtual P' is created as a consequence of a fixed N:P ratio in pig manure, assumed in the MGLP model[2].

Combining nutrient balances of the pig sector and the arable sector yields the balance for the regional farming system (Table 5.4). Internal flows between the pig sector and the arable sector (pig manure and feed grains) have 'disappeared' from this balance. N and P surpluses in the region are the sum of the surpluses in the arable and pig sector, amounting to 100 kg N and 1 kg P ha^{-1}, respectively.

Restricting NO_3-N and NH_3-N loss to 34 and 19 kg ha^{-1}, respectively, reduces labour income in the arable sector by 17% to € 818 ha^{-1} (Table 5.2). Simultaneously, labour income in the pig sector increases to € 156 ha^{-1}, related to the adoption of free range pig production. Associated regional labour income is € 974 ha^{-1} (11% reduction). The design of the crop rotation is unaffected (Table 5.2). Restricting leaching, however, limits crop production at economically optimal yields, because these crop production activities show relatively high leaching losses (see Table 3.10). Hence, N supply to arable crops is reduced and, with the exception of onion, crops are only partially cultivated

[2] Small deviations between P-inputs and outputs in the pig sector also occur in other optimisations reported in this chapter, but will henceforth not be mentioned.

Table 5.2. Key characteristics of the arable and pig sectors, as part of a specialised farming system, maximising labour income in the arable sector, *without and with restrictions on N-losses.*

	without restrictions on N-losses	with restrictions on N-losses
Ratio dairy farming : arable cropping	0 : 100	0 : 100
Goals		
income arable sector (€ ha^{-1})	**926**	**818**
income pig sector (€ ha^{-1})	80	156
regional income (€ ha^{-1})	1006	974
NO_3-N loss (kg ha^{-1})	58	34
NH_3-N loss (kg ha^{-1})	30	19
Crop rotation	w. wheat - w. potato - onion - s. beet	w. wheat - w. potato - onion - s. beet
N fertilisation crop rotation (kg ha^{-1} arable crops)		
mineral fertiliser	108	72
manure	85	52
total	193	124
Animal data		
conventional pig places ha^{-1}	7.2	1.5
free range pig places ha^{-1}	0.0	2.4

at economically optimal yields. N supply is reduced by both reducing manure-N supply (from 85 to 52 kg ha^{-1}) and mineral N supply (from 108 to 72 kg ha^{-1}). Averaged over the crop rotation, annual total-N input in mineral fertiliser and pig manure is 124 kg ha^{-1}, of which 92 kg is effective.

Reduced manure application opportunities limit animal production. This is expressed in a reduced number of pig places in the region (from 7.2 to 3.9 per ha). As pigs are partly held in a free range system, both pig slurry and solid pig manure is produced. About 80 kg total-N per ha is applied as slurry following winter wheat and onion, combined with a catch crop. These quantities are such

Table 5.3. Agronomic and MINAS nutrient balances of the arable and pig sectors as part of a specialised farming system, maximising labour income in the arable sector, *without restrictions on N-losses. (All data in kg N or P per ha).*

	Arable sector					Pig sector			
	agronomic		MINAS			agronomic		MINAS	
	N	P	N	P		N	P	N	P
Inputs					**Inputs**				
deposition	30	1	-	-	piglets	13	3	13	3
mineral fertiliser	108	6	108	-	compound feeds	109	22	109	22
animal manure	85	21	85	21	feed grains	42	7	40	7
					straw	0	0	0	0
Total inputs	223	27	193	21	Total inputs	165	32	162	32
Outputs					**Outputs**				
crop products	144	26	179	30	pigs	59	12	55	12
					manure	85	21	85	21
					'unavoidable' N-loss	-	-	30	-
Total outputs	144	26	179	30	Total outputs	144	33	170	33
Surpluses					**Surpluses**				
Agronomic surplus	79	1	-	-	Agronomic surplus	20	-1	-	-
MINAS surplus	-	-	14	-9	MINAS surplus	-	-	-8	-1
Levy-free surplus	-	-	100	9					

that all readily available mineral N can be taken up by the catch crops. Solid pig manure is applied in spring, preceding ware potato cultivation. Reduction of NH_3 -N volatilisation is partly accomplished by reducing the number of pig places in the region, and further by keeping these pigs in low-emission housing systems.
Agronomic N and P surpluses in the region amount to 39 and 1 kg ha^{-1}, respectively. Total N-loss exceeds regional N surplus, indicating that organic soil-N reserves are depleted. MINAS surpluses in the arable and pig sectors are such that no levies are paid (data not shown).

Table 5.4. Agronomic regional nutrient balances of the specialised farming system, maximising labour income in the arable sector *without restrictions on N-losses. (All data in kg N or P per ha).*

	N	P
Inputs		
deposition	30	1
mineral fertiliser	108	6
piglets	13	3
compound feeds	109	22
Total inputs	261	32
Outputs		
crop products	102	19
pigs	59	12
Total outputs	161	31
Surplus	100	1

Pig sector

The pig sector competes with the dairy sector for limited manure application opportunities within the region. Hence, if labour income is maximised for the pig sector, dairy farming is not selected and all land is assigned to arable crops (Table 5.5). Maximum labour income in the pig sector is € 421 ha^{-1}, the associated maximum regional income is € 1 261 ha^{-1}. Labour income in the arable sector is € 840. NO_3-N loss is 41 kg ha^{-1} and NH_3-N loss 34 kg ha^{-1}. The number of pig places in the region is 6.6. All pigs are kept in a free range system and are maximally fed crushed winter wheat. Total feeding costs in the pig sector amount to € 51 per free range pig delivered. If free range pigs had been fed standard compound feeds, feeding costs per pig delivered would amount to € 54. Hence, according to model assumptions, wheat feeding increases labour income by € 3 per free range pig delivered compared with feeding standard compound feeds. Scholten *et al.* (1997) found wheat feeding to result in about € 1 lower feeding costs per pig delivered. The larger reduction in feeding costs under wheat feeding found in this study is related to the slightly lower wheat price used. Cost advantages of wheat feeding are sensitive to prices of standard compound feeds relative to prices of wheat and supplementary compound feeds.

Selected crops are 1:3 winter wheat and sugar beet and 1:6 onion and ware potato. Food crops are cultivated at economically optimal yields. Winter wheat is cultivated at the lowest defined yield. Annual total N-input in the crop rotation with mineral fertiliser and pig manure is 164 kg ha^{-1}, of which 105 kg is effective. About 80 kg total-N per ha is applied as pig slurry with a catch crop on 50% of the area, i.e. following the two winter wheat crops and the onion crop, contributing to N supply of sugar beet and winter wheat. The quantities are such, that all readily available mineral N from slurry can be taken up by the catch crops. Pig slurry is applied at 100 kg total-N per ha following sugar beet on half the area, without a catch crop and contributing to N supply of ware potato. Solid pig manure is applied in spring and contributes to N supply of winter wheat. The area allocated to winter wheat is larger than under maximum income in the arable sector (Tables 5.2 and 5.5), with as ‘side-effects’ a reduced ware potato and onion area and an increased sugar beet area. Rationale is that sufficient wheat is produced for pig feeding. From the perspective of labour income in the arable sector, the design of the crop rotation is sub-optimal, resulting in a 10% reduction in labour income in that sector.

Table 5.5 shows that maximising labour income in the pig sector results in fewer pig places per ha but an equal manure-N production, than the farming system with maximum labour income in the arable sector. This is explained by the larger N excretion per pig place in free range systems than in conventional housing systems (see Table 3.15). Given the limit to manure application in the arable sector (85 kg N ha^{-1}), N excretion per pig place is the key factor in determining the number of pig places in the region, and should be as low as possible. However, higher N excretion per pig place in free range systems is accepted as the slightly lower number of pig places in the region is more than compensated by the higher price per free range pig delivered. The ‘aim’ to minimise N excretion as much as possible explains the cultivation of winter wheat at the lowest defined yield, hence with lower N content.

MINAS N surpluses in both the arable and the pig sector are negative (Table 5.6). The MINAS N surplus in the pig sector has a large negative value as a result of the large ‘unavoidable’ N-loss term in MINAS for pigs in housing systems with bedding (see Table 5.1: 8.6 kg N per pig place per year). According

to assumptions in the MGLP model, NH_3-N loss per pig place is ‘only’ 3.1 kg. MINAS P surplus in the arable sector is -10 kg ha^{-1} and MINAS P surplus in the pig sector is 1. The regional nutrient balance (Table 5.7) shows that N and P surpluses are 80 and 1 kg per ha, respectively.
Restricting NO_3-N and NH_3-N loss to 34 and 19 kg ha^{-1}, respectively, reduces maximum labour income in the pig sector by 22% to € 327 ha^{-1} (Table 5.5).
Associated labour income in the arable sector is € 505 ha^{-1}, hence regional income is € 832 ha^{-1} (34% reduction). The number of free range pig places in the region is reduced from 6.6 to 5.1 ha^{-1}. Fewer pig places reduces NH_3-N emission from stables and during application of manure. NH_3-N emission is further

Table 5.5. Key characteristics of the pig and arable sectors, as part of a specialised farming system, maximising labour income in the pig sector, *without and with restrictions on N-losses.*

	without restrictions on N-losses	with restrictions on N-losses
Ratio dairy farming : arable cropping	0 : 100	0 : 100
Goals		
income pig sector (€ ha^{-1})	**421**	**327**
income arable sector (€ ha^{-1})	840	505
regional income (€ ha^{-1})	1261	832
NO_3-N loss (kg ha^{-1})	41	34
NH_3-N loss (kg ha^{-1})	34	19
Crop rotation	s. beet - w. wheat - onion - s. beet - w. wheat - w. potato	w. potato - w. wheat - onion - w. wheat
N fertilisation crop rotation (kg ha^{-1} arable crops)		
mineral fertiliser	79	77
manure	85	66
total	164	143
Animal data		
conventional pig places ha^{-1}	0.0	0.0
free range pig places ha^{-1}	6.6	5.1

Table 5.6. Agronomic and MINAS nutrient balances of the arable and pig sectors as part of a specialised farming system, maximising labour income in the pig sector *without restrictions on N-losses. (All data in kg N or P per ha).*

	Arable sector					Pig sector			
	agronomic		MINAS			agronomic		MINAS	
	N	P	N	P		N	P	N	P
Inputs					**Inputs**				
deposition	30	1	-	-	piglets	25	3	12	3
mineral fertiliser	79	6	79	-	compound feeds	99	21	99	21
animal manure	85	21	85	21	feed grains	47	8	49	9
					straw	1	0	1	0
Total inputs	194	28	164	21	Total inputs	159	32	161	33
Outputs					**Outputs**				
crop products	135	26	177	31	pigs	54	11	51	11
					manure	85	21	85	21
					'unavoidable' N-loss	-	-	57	-
Total outputs	135	26	177	31	Total outputs	139	32	193	32
Surpluses					**Surpluses**				
Agronomic surplus	60	2	-	-	Agronomic surplus	20	0	-	-
MINAS surplus	-	-	-13	-10	MINAS surplus	-	-	-31	1
Levy-free surplus	-	-	100	9					

reduced by substituting sugar beet, a crop inducing NH_3-N emission (see Table 3.10), by winter wheat. Abandonment of sugar beet cultivation causes a sharp reduction in labour income in the arable sector, to only 60% of maximum labour income in the arable sector complying with environmental goals. With a reduced number of pig places in the region and an increased winter wheat area, produced winter wheat can only partially be fed to pigs, while another part is sold to the external market. To comply with the restriction on leaching, all but one of the arable crops are cultivated at economically sub-optimal yields. Onion is cultivated at the highest defined yield. Pig slurry is applied following the two winter wheat crops and after the onion crop. Slurry application is combined with a catch crop and contributes to N supply of ware potato, onion and winter wheat. Applied quantities are such, that all readily available mineral N can be taken up by the catch crops. Solid pig manure is applied in spring, contributing to N supply of onion. Annual total N-input with mineral fertiliser and pig manure is 143 kg ha^{-1}, of which 100 kg is effective.

Agronomic N and P surpluses in the region amount to 51 and 2 kg ha^{-1}, respectively. Total N-loss exceeds regional N surplus, indicating that organic soil-N reserves are depleted. MINAS P surplus in the pig sector is zero and other MINAS surpluses are negative.

Dairy sector

If labour income is maximised for the dairy sector without restrictions on N-losses, all available land is assigned to dairy farming (Table 5.8). Maximum labour income in this sector is € 1 858 ha^{-1} and equals maximum regional labour income, because the entire region is used for just one sector. NO_3-N leaching is 48 kg ha^{-1} and NH_3-N volatilisation 56 kg. Seventy-four percent of the

Table 5.7. Agronomic regional nutrient balances of the specialised farming system, maximising labour income in the pig sector *without restrictions on N-losses. (All data in kg N or P per ha).*

	N	P
Inputs		
deposition	30	1
mineral fertiliser	79	6
piglets	12	3
compound feeds	99	21
Total inputs	221	30
Outputs		
crop products	86	18
pigs	54	11
Total outputs	141	29
Surplus	80	1

land is used as grassland, and 26% for silage maize cultivation. Effective N input per ha grassland in mineral fertiliser and slurry is 353 kg. Maize is cultivated at the highest defined yield. Effective N input per ha maize is 104 kg, entirely applied as slurry. Slurry application in maize accounts for 70% of the total leaching loss. Stocking rate is 2.60 dairy cows ha^{-1}, and milk production 20 771 kg ha^{-1}. All cattle are kept in zero grazing systems in standard stables. Dairy cows produce 8 000 kg milk per year. Zero-grazing is more expensive than grazing, but grass yields are higher and energy requirements of animals kept indoors are lower than those of grazing animals. Hence, under zero-grazing a higher milk yield per ha can be achieved. Selection of zero-grazing indicates that higher costs are offset by higher production. Selection of maize cultivation on 26% of the available area is explained by the lower N-content of maize compared to grass - resulting in a lower N-excretion per dairy cow compared to a grass-based diet -, and to negative organic N balances associated with maize cultivation. Both characteristics allow more cows per ha, as is explained in more detail in Section 5.4.4. Concentrate use per dairy cow is 2 431 kg. The feed ration of dairy cows in winter is based on grass silage, maize silage and concentrates. This dairy farming system represents one of the most intensive systems in terms of production per ha under present manure policies and defined production activities.

Agronomic N and P surpluses are 236 and 20 kg per ha, respectively, while these surpluses according to MINAS equal 151 and 9 kg per ha (Table 5.9). Levy-free surpluses are 159 kg N and 9 kg P ha^{-1}. Hence, the MINAS surpluses do not exceed levy-free surpluses, and this permits the standardised manure production to exceed 170 kg N per ha arable land - maize in this case - and 250 kg per ha grassland. This excess is 129 kg N per ha. The MINAS P-surplus equals the levy-free surplus. The MINAS system therefore restricts labour income and probably N-emissions in the dairy sector.

Restricting NO_3-N and NH_3-N loss to 34 and 19 kg ha^{-1}, respectively, reduces labour income in the dairy sector by 26% to € 1 368 ha^{-1} (Table 5.8). More land is under grass, at the expense of silage maize cultivation. Despite resulting in high leaching loss, maize is cultivated at the highest defined yield, with N fertilisation entirely as slurry. Stocking rate is reduced from 2.60 to 1.92 dairy cows per ha and milk production from 20 771 to 15 370 kg. Effective N input per ha grassland is drastically reduced from 353 to 190 kg. All cattle are kept in a day-and-night grazing system, partly in standard stables and partly in low-

Table 5.8. *Key characteristics of the dairy sector,* maximising labour income in the dairy sector, *without and with restrictions on N-losses.*

	without restrictions on N-losses	with restrictions on N-losses
Ratio dairy farming : arable cropping	100 : 0	100 : 0
Goals		
income dairy sector (€ ha^{-1})	**1858**	**1368**
regional income (€ ha^{-1})	1858	1368
NO_3-N loss (kg ha^{-1})	48	34
NH_3-N loss (kg ha^{-1})	56	19
Land use		
permanent grassland (%)	74	84
continuously cropped maize (%)	26	16
N fertilisation maize (kg ha^{-1} maize)		
mineral fertiliser	0	0
slurry	462	462
total	462	462
N fertilisation grassland (kg ha^{-1} grassland)		
mineral fertiliser	232	155
slurry	263	72
total	495	227
Animal data		
dairy cows ha^{-1}	2.60	1.92
milk production (kg ha^{-1})	20771	15369
concentrates per dairy cow (kg)	2431	2410

emission stables. This shift to grazing systems is explained by their lower NH_3-N emission, assumed in this study. The 'price' of grazing systems is lower grassland productivity. Concentrate use is of the same order of magnitude as under maximum labour income in the dairy sector. The feed ration in winter is based on maize silage and concentrates.

Table 5.9. Agronomic and MINAS nutrient balances of the dairy sector, maximising labour income in the dairy sector *without restrictions on N-losses. Data in kg ha⁻¹.*

	agronomic		MINAS	
	N	P	N	P
Inputs				
deposition	30	1	-	-
mineral fertiliser	172	11	172	-
concentrates	158	31	158	31
Total inputs	360	43	330	31
Outputs				
milk	110	19	110	19
manure	0	0	0	0
animals	14	4	14	4
'unavoidable' N-loss	-	-	55	-
Total outputs	124	23	179	23
Surpluses				
Agronomic surplus	236	20	-	-
MINAS surplus	-	-	151	9
Levy-free surplus	-	-	159	9

Agronomic surpluses are 202 kg N and 13 kg P ha^{-1}. MINAS N and P surpluses are 149 and 9 kg ha^{-1}, respectively. Levy-free surpluses are 167 kg N ha^{-1} and 9 kg P ha^{-1}. Because MINAS surpluses do not exceed levy-free surpluses, standardised manure production in excess of 170 kg N per ha maize and 250 kg per ha grassland (28 kg N ha^{-1}) can be applied within the dairy sector.

5.3.2 Best attainable values and solution area for regionally specialised farming

The solution area for regionally specialised farming is established by maximising the sum of labour incomes in the arable, pig and dairy sector - constituting the regional labour income -, while gradually tightening restrictions on N-losses. A preliminary series of calculations showed that, without additional restrictions, the large majority of farming systems underlying the solution area would refer to 100% dairy farming. This is not surprising, as the dairy sector is by far the most profitable. However, it strongly differs from the current situation in the province Flevoland, where about 70% of the land is used for arable crops and only about 15% for dairy farming (Wijnen, 1999). Dominance of arable cropping in the study area has an historical background and is linked to the favourable production situation. It is unlikely that in future the entire study area will be transformed to dairy farming, despite it being most profitable. One reason is that national milk production is restricted by the national milk quota. A second reason is that large scale conversion to dairy farming would reduce its profitability and boost that of arable cropping. These factors are not taken into account in the MGLP model. Therefore, the solution area for regionally specialised farming is calculated, based on optimisations with one additional restriction, that at least 50% of the area should be under arable crops. The choice for a minimum of 50% under arable crops is arbitrary.

Adding the restriction that a minimum of 50% should be under arable crops, maximum regional income is € 1 647 ha^{-1}. Associated sectoral NO_3-N and NH_3-N loss amount to 54 and 70 kg ha^{-1}, respectively (optimisation 1 in Table 5.10), to be accepted in the arable and dairy sector, respectively. Minimum sectoral leaching loss is the maximum of minimum leaching loss in the dairy sector and minimum leaching loss in the arable sector. This value equals 18 kg ha^{-1}, and refers to the minimum leaching loss in the arable sector. Maximum regional labour income at minimum leaching is € 715 ha^{-1}, but then 38 kg NH_3-N loss ha^{-1} in the dairy sector has to be accepted (optimisation 2). Minimum sectoral NH_3-N volatilisation at minimum leaching loss is also 38 kg ha^{-1} (optimisation 3), hence at minimum sectoral leaching, no variation in sectoral volatilisation loss is possible. Minimum sectoral NH_3-N volatilisation is zero, when all land is used by the arable sector. Maximum labour income without NH_3-N loss is € 487 ha^{-1} (optimisation 4), but then 44 kg N ha^{-1} sectoral leaching has to be accepted. Minimum sectoral NO_3-N leaching at minimum NH_3-N emission is 22 kg N ha^{-1} (optimisation 5), with associated labour income of € 26 ha^{-1}.

The best attainable values of each single goal define the outer boundaries of the solution area for regionally specialised farming. The contour plot representing this solution area is given in Figure 5.1, with sectoral NO_3-N leaching on the x-axis and sectoral NH_3-N volatilisation on the y-axis; (x, y)

co-ordinates are connected by labelled iso-labour income lines (z-co-ordinate). Each co-ordinate (x, y, z) is optimal, because none of the goal variables can be improved without sacrificing one of the others, hence without moving to another point in the contour plot. Numbers 1 through 5 correspond to optimisation numbers in Table 5.10. The horizontal dashed line indicates the policy standard for NH_3-N emission. The vertical line is the policy standard for NO_3-N emission. The shape of the iso-labour income lines in Figure 5.1 shows that NO_3-N leaching and NH_3-N emission are interchangeable goals. For example, a labour income of € 1 500 ha^{-1} can be attained with sectoral leaching anywhere between about 50 and 30 kg N ha^{-1}, and with sectoral volatilisation between 38 and 62 kg N ha^{-1}. However, if the value of one of these goals is in the lower part of its range, € 1 500 ha^{-1} labour income can only be attained if an unfavourable value for the other goal is accepted. The extreme points are at 30 kg ha^{-1} sectoral leaching, when 62 kg ha^{-1} sectoral NH_3-N volatilisation has to be accepted, and at 38 kg ha^{-1} sectoral NH_3-N volatilisation, when 50 kg ha^{-1} sectoral leaching has to be accepted.

Table 5.10. Extreme values of three goals optimised (bold) and associated values of the other goal variables in regionally specialised farming systems, with restriction that at least 50% should be under arable cropping.

Goal variable 1	Goal variable 2	Optimisation number	Labour income (€ ha^{-1})	NO_3-N leaching (kg ha^{-1})	NH_3-N emission (kg ha^{-1})
Labour income (max)	-	1	**1647**	54	70
NO_3-N leaching (min)	labour income	2	715	**18**	38
	NH_3-N emission	3	715	**18**	38
NH_3-N emission (min)	labour income	4	487	44	**0**
	NO_3-N emission	5	26	22	**0**

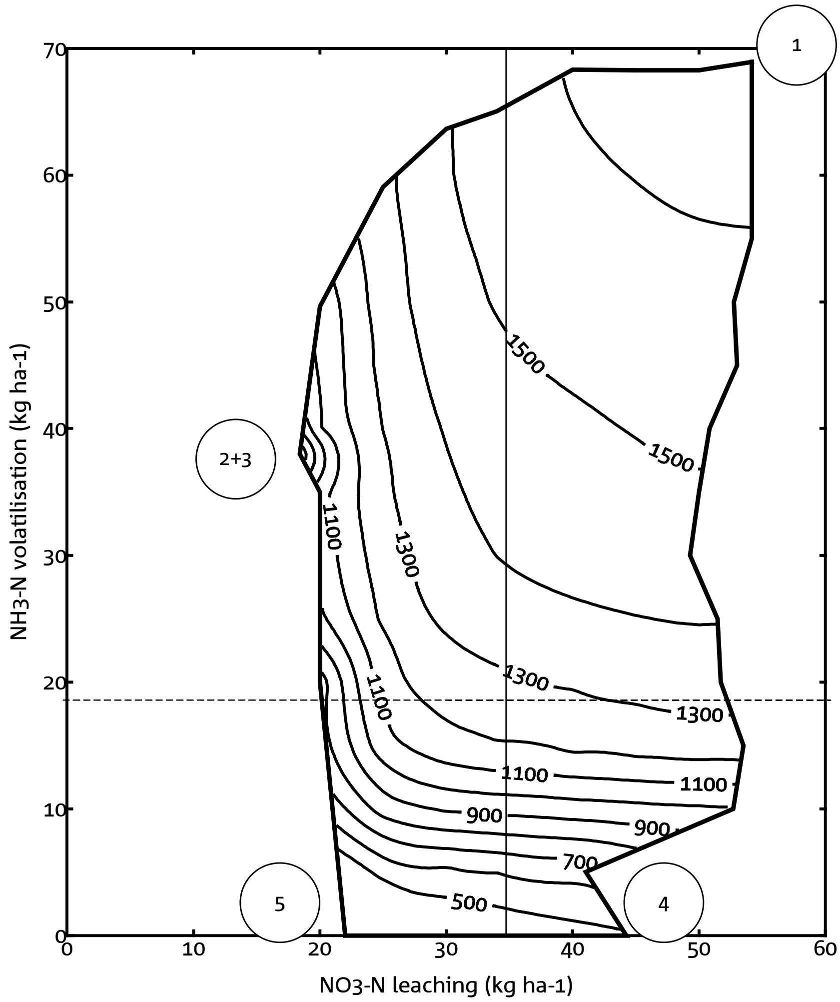

Figure 5.1. *The solution area for regionally specialised farming systems, with restriction that at least 50% should be under arable crops, as defined by optimisation of the goals sectoral NO_3-N leaching (x-axis, kg N ha^{-1}), sectoral NH_3-N emission (y-axis, kg N ha^{-1}) and regional labour income (labelled lines, € ha^{-1}). Numbers 1 through 5 correspond to optimisation numbers in Table 5.10.*

Configuration of the specialised farming system without restrictions on N-losses

If labour income is maximised without restrictions on leaching and volatilisation losses (optimisation 1 in Table 5.10; point 1 in Figure 5.1), the ratio of dairy farming and arable cropping is 50:50 (Table 5.11). Pig production is absent from the region. Maximum regional labour income is € 1 646, of which 70% is generated in the dairy sector. NO_3-N leaching in the region is 48 kg ha^{-1} and NH_3-N loss 39 kg ha^{-1}. Leaching loss is 42 kg NO_3-N ha^{-1} in the dairy

Table 5.11. Key characteristics of the specialised farming system, maximising regional labour income, *without and with restrictions on N-losses.*

	without restrictions on N-losses	with restrictions on N-losses
Ratio dairy farming : arable cropping	50 : 50	50 : 50
Goals		
income arable sector (€ ha^{-1})	501	418
income pig sector (€ ha^{-1})	0	100
income dairy sector (€ ha^{-1})	1145	745
regional income (€ ha^{-1})	**1646**	**1262**
NO_3-N loss arable sector (kg ha^{-1})	54	34
NO_3-N loss dairy sector (kg ha^{-1})	42	34
NO_3-N loss region (kg ha^{-1})	48	34
NH_3-N loss arable sector (kg ha^{-1})	10	19
NH_3-N loss dairy sector (kg ha^{-1})	70	19
NH_3-N loss region (kg ha^{-1})	40	19
Land use		
permanent grassland (%)	40	42
continuously cropped maize (%)	10	8
arable crops (%)	50	50
Crop rotation	w. wheat - w. potato - onion - s. beet	w. wheat - w. potato - onion - s. beet
N fertilisation crop rotation (kg ha^{-1} arable crops)		
mineral fertiliser	110	40
manure	85	76
total	195	116
N fertilisation maize (kg ha^{-1} maize)		
mineral fertiliser	0	0
slurry	462	462
total	462	462
N fertilisation grassland (kg ha^{-1} grassland)		
mineral fertiliser	251	171
slurry	265	61
total	516	232
Animal data		
pig places	0	1.5
dairy cows per ha dairy farming	3.30	2.23
milk production (kg regional ha^{-1})	13195	8907
milk production (kg ha^{-1} dairy farming)	26390	17815
concentrates per dairy cow (kg)	2369	2541

sector and 54 kg NO_3-N ha^{-1} in the arable sector. NH_3-N loss is 70 (dairy sector) and 10 (arable sector) kg ha^{-1}. The design of the crop rotation equals that under maximum income in the arable sector and crops are fertilised at economically optimal yields. Winter wheat is used as feed in the dairy sector. Maximum permitted slurry-N is applied in the arable sector, i.e. 85 kg N per ha assigned to arable cropping. Two hundred and fifty kg total-N ha^{-1} is applied following onion and 94 kg total-N ha^{-1} following winter wheat, contributing to N supply of ware potato and sugar beet, respectively. Both applications are combined with a catch crop, however, only after winter wheat all readily available mineral N can be taken up by the catch crop. Averaged over the crop rotation, annual total-N input is 195 kg N ha^{-1}, of which 136 kg is effective. As under maximum income in the dairy sector, all cattle are kept in zero grazing systems and in standard stables. Stocking rate in the region is 1.65 dairy cows per ha. Of the land assigned to the dairy sector, 20% is under maize with N fertilisation entirely as slurry. Maize cultivation and its fertilisation account for 80% of the total leaching loss in the dairy sector. The feed ration in winter consists of a mixture of grass, cereal and maize silage, wheat grains and concentrates. Total-N and effective N-application rate on grassland (516 and 375 kg ha^{-1}, respectively) are similar to those under maximum income in the dairy sector. The dairy sector has become less land-based than under maximum sectoral income: additional feed is imported from the arable sector and about 20% of cattle slurry produced is exported to the arable sector. This allows a higher milk production per ha dairy farming (26 390 kg), than under maximum income in the dairy sector (20 771 kg).

Agronomic N and P surpluses in the dairy sector are 237 and 23 kg per ha dairy farming, respectively (Table 5.12). MINAS N and P surpluses in the dairy sector are 127 and 9 kg per ha dairy farming, respectively, and hence do not exceed levy-free surpluses. Consequently, standardised manure-N production and application in the dairy sector can exceed the maximum, set in the Nitrate Directive. This excess is 70 kg N per regional ha. Agronomic surpluses in the arable sector are 81 kg N and 0 kg P per ha arable cropping. MINAS N surplus in the arable sector is 27 kg ha^{-1} arable cropping and MINAS P surplus -16 kg. These MINAS surpluses are lower than the levy-free surpluses, hence no levies are paid. Combining nutrient balances of the dairy sector and the arable sector yields the balance for the regional farming system (Table 5.13). N and P surpluses in the region are the weighed sums of these surpluses in the arable and dairy sector, amounting to 159 kg and 11 kg ha^{-1}, respectively.

Table 5.12. Agronomic and MINAS nutrient balances of the dairy and arable sector as part of a specialised farming system, maximising regional labour income *without restrictions on N-losses. (All data in kg N or P per ha dairy farming and arable cropping, respectively.)*

	Dairy sector					Arable sector			
	agronomic		MINAS			agronomic		MINAS	
	N	P	N	P		N	P	N	P
Inputs					**Inputs**				
deposition	30	1	-	-	deposition	30	1	-	-
mineral fertiliser	199	13	199	-	mineral fertiliser	110	14	110	-
concentrates	210	42	210	42	animal manure	85	12	85	12
roughages	41	8	41	8					
Total inputs	480	64	449	50	Total inputs	225	27	195	12
Outputs					**Outputs**				
milk	140	24	140	24	crop products	144	27	168	28
manure	85	12	85	12					
animals	18	5	18	5					
'unavoidable' N-loss	-	-	79	-					
Total outputs	243	41	322	41	Total outputs	144	27	168	28
Surpluses					**Surpluses**				
Agronomic surplus	237	23	-	-	Agronomic surplus	81	0	-	-
MINAS surplus	-	-	127	9	MINAS surplus	-	-	27	-16
Levy-free surplus	-	-	163	9	Levy-free surplus	-	-	100	9

Configuration of the specialised farming system with restrictions on sectoral N-losses

The MGLP model has many options to comply with restrictions on sectoral N-losses. For reasons of transparency, the configuration of the specialised farming system complying with the policy standards is explained along two lines of reasoning. First, changes in optimal design induced by stepwise tightening the restriction on NH_3-N volatilisation at a fixed NO_3-N loss of 34 kg

Table 5.13. Agronomic nutrient balance of the specialised farming system, maximising regional labour income *without restrictions on N-losses. (All data in kg N or P per ha).*

	N	P
Inputs		
deposition	30	1
mineral fertiliser	154	14
concentrates	100	20
Total inputs	284	35
Outputs		
crop products	46	9
milk	70	12
animals	9	3
Total outputs	125	24
Surplus	159	11

N ha^{-1} will be analysed. Note that this corresponds with an analysis of changes in optimal design of farming systems following the vertical line in Figure 5.1 from the outer limit of the solution area up to (x, y)-co-ordinate (34,19). Next, changes induced by stepwise tightening the restriction on NO_3-N leaching at a fixed NH_3-N loss of 19 kg N ha^{-1} will be discussed. This corresponds with following the horizontal dotted line in Figure 5.1 up to (x, y)-co-ordinate (34,19). Key characteristics of the specialised farming system complying with environmental standards are summarised in Table 5.11.

If NO_3-N leaching in each sector is restricted to 34 kg N ha^{-1} with NH_3-N unrestricted, the ratio of dairy farming and arable cropping is 50:50. In addition to dairy farming and arable cropping, 0.9 free range pig places per ha are selected. Maximum regional labour income is € 1 549 ha^{-1} (Figure 5.2a) and regional NH_3-N emission 41 kg ha^{-1}. NH_3-N volatilisation is 65 kg per ha used for dairy farming and 16 kg per ha arable crops (including NH_3-N emission from pigs' stables) (Figure 5.2b). Leaching loss in both the arable and dairy sector is 34 kg N ha^{-1}, hence the restriction on leaching limits production in both sectors. Labour incomes generated in the dairy, arable and pig sector amount to

€ 1 053, 440 and 55 respectively (Figure 5.2a). As under maximum regional income without restrictions on N-losses, all cattle are kept in zero grazing systems and in standard stables. Milk production per ha dairy farming is reduced by 2 000 kg to 24 440 kg ha^{-1} (Figure 5.2d). Fifteen percent of produced cattle slurry is exported to the arable sector. Selected crops in the arable sector are 1:3 sugar beet and winter wheat and 1:6 ware potato and onion. Winter wheat is entirely used as feed in the dairy and pig sectors. Sugar beet is partly fertilised at economically optimal yield and partly at economically sub-optimal yield. All other crops are fertilised at economically sub-optimal yields. Compared to the situation under maximum regional income, effective N application in the crop rotation is halved to 67 kg ha^{-1} (Figure 5.2c). The amount of manure-N applied in the arable sector is 10 kg below the maximum permitted, i.e. 75 kg N per ha arable crops, accounting for 35% of the effective N requirement of crops. Manure-N applied to arable crops is more susceptible to leaching than mineral N. Hence, the lower the proportion of manure-N in crop fertilisation, the higher yield levels can be at which the arable crops are cultivated. However, the considerable amounts of manure-N used in crop fertilisation show that, from the perspective of regional income, it is attractive to accept cultivation of arable crops at lower yields, enabling more animal production in the region.

With NH_3-N emission unrestricted, that emission in the dairy sector (65 kg NH_3-N per ha dairy farming) is much higher than in the arable plus pig sector (Figure 5.2b). Hence, if maximum permitted NH_3-N emission for each sector is tightened to a value below 65 kg ha^{-1}, that almost exclusively restricts the dairy sector (see Figures 5.2a, b, c, d). For example, in the range of permitted NH_3-N loss between 65 and 45 kg ha^{-1}, income reduction in the dairy sector is about 20%, while income loss in the arable sector is only 5% (Figure 5.2a). Over the same range, the number of free range pig places in the region increases from 0.9 to 3.2, and labour income in the pig sector from € 55 to 204 ha^{-1} (Figure 5.2a). This increase in pig production has become feasible, because less manure is produced in the dairy sector, creating opportunities for the pig sector to export manure to the arable sector. As a result of increased pig production, NH_3-N volatilisation in the pig and arable sectors increases to 33 kg NH_3-N per ha arable cropping (Figure 5.2b). Apart from the substitution of milk production by pig production, other changes predominantly occur in the dairy sector. Less cattle are kept in zero grazing systems, and more in day-and-night

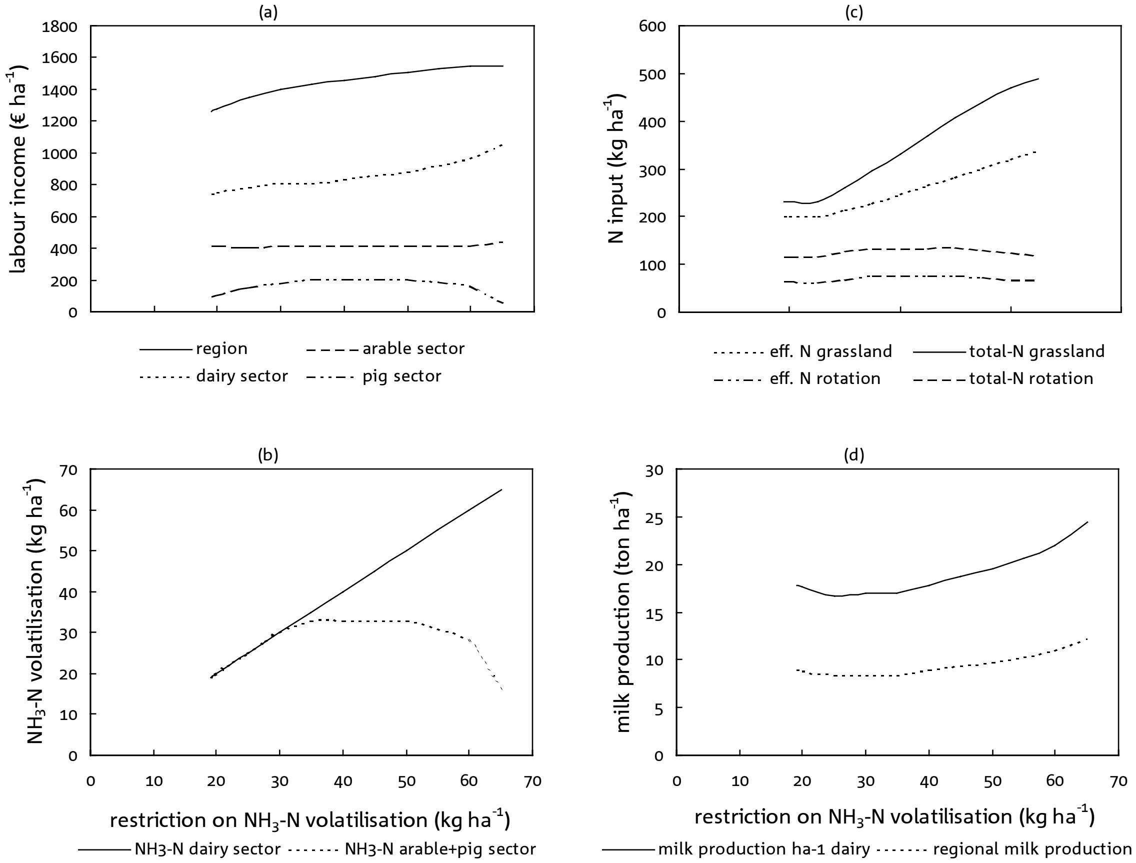

Figure 5.2. *Changes induced in specialised farming, maximising labour income while gradually tightening the restriction on NH_3-N volatilisation at a maximum leaching loss of 34 kg N ha^{-1}: (a) regional labour income and labour income in the dairy, arable and pig sectors (in € per regional ha), (b) NH_3-N volatilisation in the dairy sector and in the arable plus pig sector (in kg per ha dairy farming and kg per ha arable cropping, respectively), (c) N fertilisation of grassland and arable crops (kg N per ha grassland and kg N per ha arable crops, respectively), and (d) milk production (ton per regional ha and per ha dairy farming). In all graphs, the x-axis denotes NH_3-N volatilisation in kg ha^{-1}.*

grazing systems, which is the consequence of lower NH_3-N emission assumed for grazing systems in this study. Extensification of the dairy sector in the range of permitted NH_3-N loss between 65 and 45 kg ha^{-1} is further reflected in a decrease in milk production per ha dairy farming (Figure 5.2d), in effective N applied per ha grassland (Figure 5.2c) and in stocking rate. Despite a tight restriction on NH_3-N loss, all cattle are housed in standard stables, because, from the perspective of maximum regional income, it is apparently more attractive to produce the maximum amount of cattle manure in cheaper standard stables combined with less productive grazing systems, than in expensive low-emission stables.

Tightening the restriction on NH_3-N volatilisation to 19 kg ha^{-1} makes it binding in both the dairy sector and the arable plus pig sectors (Figure 5.2b). The ratio of dairy farming and arable cropping is maintained at 50:50. Changes in the arable sector are minimal. In the pig sector, the number of free range pig places, hence also labour income, is reduced as the restriction on NH_3-N volatilisation becomes binding in the arable plus pig sector (from 33 kg NH_3-N downwards; Figures 5.2a and b). Major changes in the dairy sector are continued extensification and adoption of low-emission stables. Extensification is reflected in reduced milk production per ha dairy farming (Figure 5.2d), reduced N-input in grassland (Figure 5.2c) and a reduced stocking rate. Seventy percent of the dairy cows is kept in low-emission stables, which is combined with grazing. Adoption of low-emission stables explains the small increase in milk production per ha in the lower range (25-19 kg) of permitted NH_3-N volatilisation (Figure 5.2d). Twenty percent of produced slurry is exported to the arable sector.

If NH_3-N volatilisation is restricted to 19 kg ha^{-1}, with NO_3-N leaching unrestricted, the ratio of dairy farming and arable cropping is 50:50. In addition to dairy farming and arable cropping, 1.2 free range pig places per ha are selected. Maximum regional labour income is € 1 319 (Figure 5.3a) and NO_3-N emission 44 kg ha^{-1}. NO_3-N leaching is 35 kg per ha dairy farming and 52 kg per ha arable crops (Figure 5.3b). Volatilisation loss in both the dairy and arable plus pig sector is 19 kg N ha^{-1}, hence the restriction on volatilisation is binding in all sectors. Labour income in the dairy, arable and pig sector amounts to € 763, 476 and 81, respectively (Figure 5.2a). Selected crops are 1:4 sugar beet, winter wheat, ware potato and onion, i.e. the same crops as under maximum regional and sectoral income. Winter wheat is entirely used as feed in the dairy and pig sectors. Except for winter wheat, all crops are cultivated at economically optimal yields. Effective N application in the crop rotation is 132 kg ha^{-1} (Figure 5.3c). The amount of manure-N applied in the arable sector corresponds with the maximum permitted (85 kg N per ha arable crops) and covers 20% of effective N requirements of crops. Stocking rate in the region is 1.2 dairy cows per ha, i.e. 2.4 per ha allocated to dairy farming. Ninety percent of the dairy herd is housed in low-emission stables, in a mixture of grazing systems. Adoption of low-emission stables indicates that, from the perspective

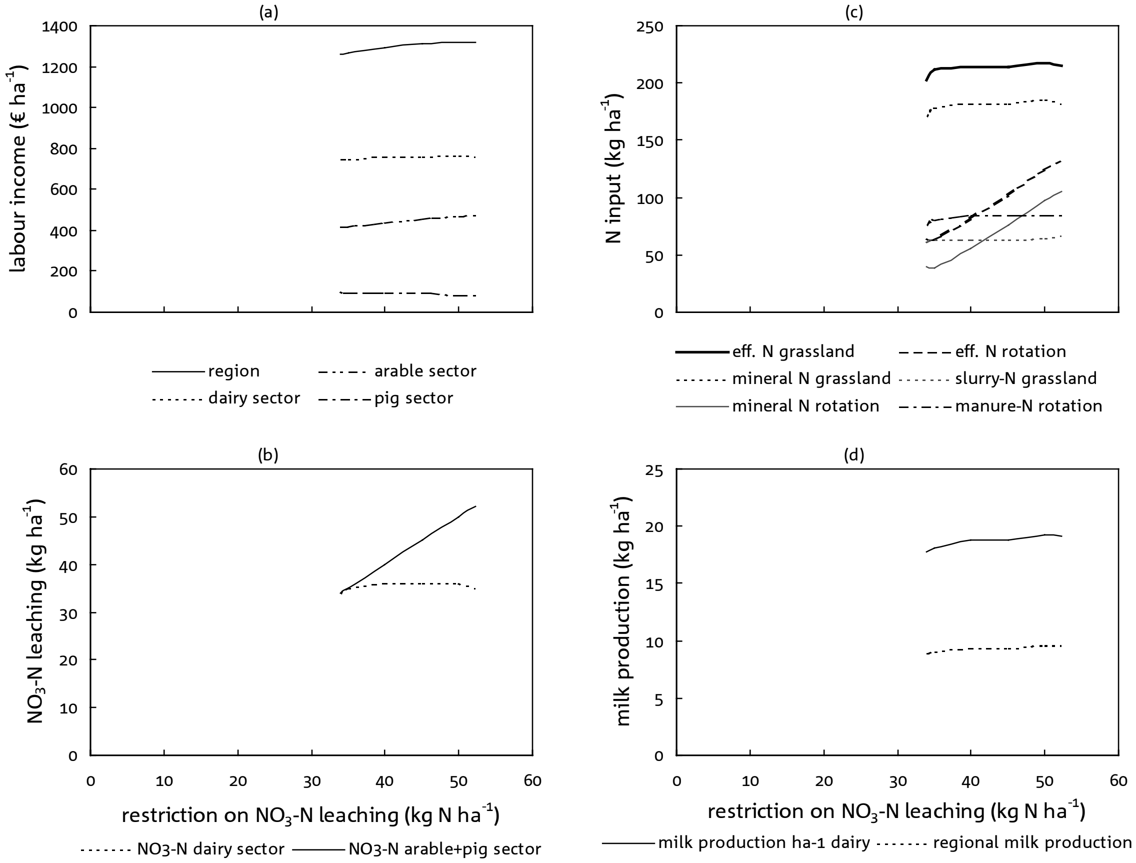

Figure 5.3. Changes induced in specialised farming, maximising labour income while gradually tightening the restriction on NO_3-N leaching at a maximum volatilisation loss of 19 kg N ha^{-1}: (a) regional labour income and labour income in the dairy, arable and pig sectors (in € per regional ha), (b) NO_3-N leaching in the dairy sector and in the arable sector (in kg per ha dairy farming and kg per ha arable cropping, respectively), (c) N fertilisation of grassland and arable crops (kg N per ha grassland and kg N per ha arable crops, respectively), and (d) milk production (ton per regional ha and per ha dairy farming). In all graphs, the x-axis denotes NO_3-N leaching in kg ha^{-1}.

of regional labour income, it is attractive to produce more milk at higher costs, instead of producing less milk at lower cost. Thirty percent of slurry produced in the dairy sector is exported to the arable sector.

NO_3-N emission in the arable sector (52 kg NO_3-N ha^{-1} arable cropping) is much higher than in the dairy sector (Figure 5.3b). Hence, restricting NO_3-N leaching to a value below 52 kg ha^{-1} primarily affects N fertilisation of arable crops (see Figure 5.3c). In principle, the arable sector can comply with a tightened restriction on NO_3-N leaching either by reducing mineral N supply or manure-N supply to arable crops. In the model, the tightened restriction is complied with almost entirely by reducing mineral N supply, while manure-N supply is about maintained at its initial value (Figure 5.3c). As a result, animal production in the region can be maintained, to the benefit of regional labour income, but arable crops have to be cultivated at lower yields.

In all situations in Figures 5.2 and 5.3, the MINAS N surplus in the dairy sector and the MINAS N and P surplus in the arable sector never exceed levy-free surpluses. Agronomic and MINAS nutrient balances of the dairy and arable sector, as part of the specialised farming system complying with the policy standards, are given in Table 5.14.

5.3.3 Best attainable values and solution area for regionally mixed farming

As in specialised farming, the solution area for mixed farming is established under the restriction that the area allocated to arable crops should be at least 50%. With that restriction, maximum regional labour income in mixed farming systems is € 2 375 (optimisation 1 in Table 5.15). Associated regional NO_3-N and NH_3-N losses are 79 and 53 kg N ha^{-1}, respectively. Minimum leaching loss is 16 kg NO_3-N ha^{-1}. Maximum labour income at minimum leaching is € 1 198 ha^{-1} with NH_3-N emission amounting to 47 kg N ha^{-1} (optimisation 2). Minimum NH_3-N emission at minimum leaching is 8 kg ha^{-1} (optimisation 3); associated labour income is € 212 ha^{-1}. Minimum NH_3-N volatilisation is 3 kg ha^{-1}. Maximum labour income at minimum volatilisation is € 467 ha^{-1} (optimisation 4), associated with 36 kg NO_3-N leaching. Minimum NO_3-N leaching at minimum NH_3-N emission is 23 kg N ha^{-1} (optimisation 5), with associated labour income amounting to € 49.

The solution area for regional mixed farming is given in Figure 5.4. The solution area for mixed farming shows two striking differences with that of specialised farming systems. First, labour income per ha can attain much higher levels than in specialised farming. Second, the solution area covers a much larger area of N-losses, particularly of NO_3-N, indicating that higher levels of labour income in mixed farming systems are associated with higher losses. The differences are explained by differences in impact of manure policy regulations on mixed versus specialised farming systems (see below).

Table 5.14. Agronomic and MINAS nutrient balances of the dairy and arable sector as part of a specialised farming system, maximising regional labour income *with restrictions on N-losses. (Data for the dairy sector in kg nutrient per ha dairy farming and data for the arable sector in kg nutrient per ha arable cropping).*

	Dairy sector					Arable sector			
	agronomic		MINAS			agronomic		MINAS	
	N	P	N	P		N	P	N	P
Inputs					**Inputs**				
deposition	30	1	-	-	deposition	30	1	-	-
mineral fertiliser	144	5	144	-	mineral fertiliser	40	10	40	-
concentrates	172	31	162	31	animal manure	76	15	76	15
roughages	9	2	9	2					
Total inputs	345	39	315	33	Total inputs	146	26	116	15
Outputs					**Outputs**				
milk	94	16	94	16	crop products	118	25	172	30
manure	36	5	36	5					
animals	12	3	12	3					
'unavoidable' N-loss	-	-	35	-					
Total outputs	142	24	177	24	Total outputs	118	25	172	30
Surpluses					**Surpluses**				
Agronomic surplus	203	15	-	-	Agronomic surplus	28	1	-	-
MINAS surplus	-	-	138	9	MINAS surplus	-	-	-56	-15
Levy-free surplus	-	-	167	9	Levy-free surplus	-	-	100	9

Configuration of the mixed farming system without restrictions on N-losses

If labour income is maximised without restrictions on N-losses (optimisation 1 in Table 5.15; point 1 in Figure 5.2), half of the area is under grassland and half is under arable crops (Table 5.16). There is no pig production in the region. Regional labour income is € 2 375, 85% originating from milk production and 15 from food crop production. NO_3-N loss is 81 kg ha^{-1} and NH_3-N loss 53 kg. Leys are combined with fodder crops silage maize and cereal silage and food crops ware potato and sugar beet. Cropping frequency of arable crops is 1:8.

Table 5.15. Extreme values of three goals optimised (bold) and associated values of the other goal variables in regionally mixed farming systems with restriction that at least 50% should be under arable cropping.

Goal variable 1	Goal variable 2	Optimisation number	Labour income (€ ha^{-1})	NO_3-N leaching (kg ha^{-1})	NH_3-N emission (kg ha^{-1})
Labour income (max)	-	1	**2375**	79	53
NO_3-N leaching (min)	labour income	2	1198	**16**	47
	NH_3-N emission	3	212	**16**	8
NH_3-N emission (min)	labour income	4	467	36	**3**
	NO_3-N emission	5	49	23	**3**

All arable crops are cultivated at economically optimal yields. Averaged over the arable crop area, annual total-N input is 413 kg ha^{-1}, of which 133 kg is effective. As opposed to specialised farming systems, there is no institutional limit on the amount of manure-N applied in arable crops, as long as MINAS surpluses of the mixed farming system do not exceed levy-free surpluses. Hence, large quantities of cattle slurry are applied to arable crops, averaging 371 kg total-N ha^{-1} arable crops and corresponding to 65% of the amount produced. Four hundred kg total-N ha^{-1} is applied in the 4th-year ley before ploughing, 640 kg total-N ha^{-1} following winter wheat and 420 kg total-N ha^{-1} following sugar beet. These slurry applications lead to very high winter leaching losses, either because readily available mineral slurry-N can only partly be taken up by the catch crop (following winter wheat), or no catch crop is used at all (following sugar beet). Annual leaching loss under the arable crop area is as high as 150 kg N ha^{-1}.

All cattle are kept in zero grazing systems and in standard stables. Stocking rate in the region is 2.49 dairy cows ha^{-1} and milk production 19 930 kg ha^{-1}. The feed ration of dairy cows in winter is based on concentrates and cereal silage, supplemented with grass and maize silage. Effective N-application rate on

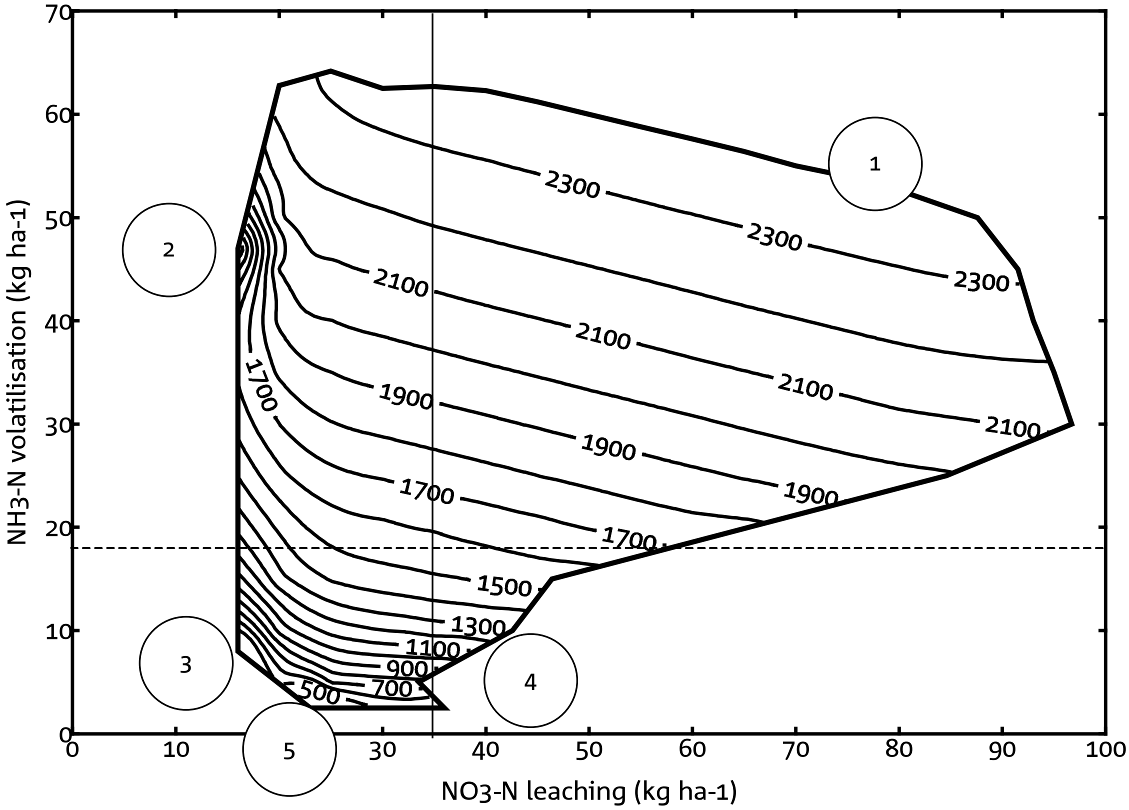

Figure 5.4. The solution area for regionally mixed farming systems with restriction that at least 50% should be under arable crops as defined by optimisation of the goals NO_3-N leaching (x-axis, kg N ha^{-1}), NH_3-N emission (y-axis, kg N ha^{-1}) and regional labour income (labelled lines, € ha^{-1}).
Numbers 1 through 5 correspond to optimisation numbers in Table 5.15.

grassland is at the highest value defined (400 kg N ha^{-1}). Total-N application rate on grassland is 505 kg ha^{-1}. Leaching under grassland is low, i.e. only 11 kg NO_3-N ha^{-1} grassland. Such a low leaching loss is feasible because cattle are kept in zero-grazing systems, avoiding high N concentrations in urine patches as present in grazing systems. Low leaching loss under grassland compensates high leaching losses under arable crops, so that at regional scale NO_3-N leaching averages 'only' 81 kg ha^{-1}. Concentrate use per dairy cow is 3 118 kg.
Agronomic N and P surpluses are 238 and 11 kg per ha, respectively (Table 5.17). These surpluses according to MINAS are 140 and 9 kg per ha, respectively, and match the levy-free surpluses (Table 5.17). As no levies are paid, standardised manure-N production can exceed the maximum set in the Nitrate Directive. This excess is 134 kg manure-N per ha.

Table 5.16. *Key characteristics of the mixed farming system,* maximising regional labour income, *without and with restrictions on N-losses.*

	without restrictions on N-losses	with restrictions on N-losses
Ratio grassland : arable crops	50 : 50	50 : 50
Goals		
income from crop production (€ ha^{-1})	345	381
income from milk production (€ ha^{-1})	2030	1198
income from pig production (€ ha^{-1})	0	0
regional income (€ ha^{-1})	**2375**	**1579**
NO_3-N leaching (kg ha^{-1})	81	34
NH_3-N volatilization (kg ha^{-1})	53	19
Land use		
leys (%)	50	50
fodder crops (%)	25	13
food crops (%)	25	37
Crop rotation	leys (1-4 years old) - s.beet - maize - w.wheat - w.potato	leys (1-4 years old) - s.beet - onion - w.wheat - w.potato
N fertilisation arable crops (kg ha^{-1} arable crops)		
mineral fertiliser	42	42
manure	371	95
total	413	137
N fertilisation grassland (kg ha^{-1} grassland)		
mineral fertiliser	306	220
slurry	199	92
total	505	312
Animal data		
pig places	0	0
dairy cows per ha grassland and fodder crops	3.32	2.36
milk production (kg regional ha^{-1})	19929	11786
milk production (kg ha^{-1} grassl.+fodder crops)	26572	18858
concentrates per dairy cow (kg)	3118	2953

Table 5.17. Agronomic and MINAS nutrient balances of the mixed farming system, maximising regional labour income *without restrictions on N-losses. (All data in kg ha*$^{-1}$*).*

	agronomic		MINAS	
	N	P	N	P
Inputs				
deposition	30	1	-	-
mineral fertiliser	174	2	174	-
concentrates	192	38	192	38
Total inputs	396	41	366	38
Outputs				
milk	106	18	106	18
crops	39	8	41	7
animals	13	4	13	4
'unavoidable' N-loss	-	-	66	-
Total outputs	158	30	226	29
Surpluses				
Agronomic surplus	238	11	-	-
MINAS surplus	-	-	140	9
Levy-free surplus	-	-	140	9

Configuration of the mixed farming system with restrictions on N-losses

As for specialised farming systems, the configuration of the mixed farming system complying with the policy standards is explained along two lines of reasoning. First, changes in optimal design induced by stepwise tightening the restriction on NH_3-N volatilisation at a fixed NO_3-N loss of 34 kg N ha^{-1} will be analysed. Next, changes induced by stepwise tightening the restriction on NO_3-N leaching at a fixed NH_3-N loss of 19 kg N ha^{-1} will be discussed. Key characteristics of the mixed farming system complying with policy standards are given in Table 5.16.

If NO_3-N leaching is restricted to 34 kg N ha^{-1} with NH_3-N unrestricted, half of the area is under grassland and half is under arable crops. The configuration of the mixed farming system much resembles that under maximum regional labour income. Hence, there is no pig production in the region and labour income is at near-maximum, amounting to € 2 354. Associated NH_3-N loss is 63 kg. As under maximum labour income, leys are combined with 1:8 fodder crops silage maize and cereal silage and 1:8 food crops ware potato and sugar beet. All arable crops, except for sugar beet, are cultivated at economically optimal yields. Slurry-N applied to arable crops averages 63 kg total-N ha^{-1} arable crops, and this is much less than under maximum regional income. Slurry is applied following winter wheat (with catch crop), following sugar beet (without catch crop) and in the 4th-year ley before ploughing. As a result of reduced slurry-N-input in arable crops, annual leaching loss under the arable crop area is reduced from 150 to 57 kg N ha^{-1}. Milk and roughage production activities largely resemble those under maximum regional income (see above). Main difference is that much more slurry is used in N fertilisation of grassland (500 vs. 200 kg slurry-N ha^{-1} grassland). Hence, slurry-N applied to arable crops under unrestricted leaching loss, is applied to grassland if leaching loss is restricted to 34 kg N ha^{-1}.

NH_3-N emission is primarily associated with production and application of animal manure and hence with animal production. Consequently, restricting ammonia volatilisation in the region will primarily reduce animal production, i.e. affect dairy farming activities. Hence, if the restriction on volatilisation is tightened, dairy farming is gradually extensified (Figure 5.5). Initially, till 40 kg permitted NH_3-N volatilisation, extensification is moderate and regional milk production is hardly affected (Figure 5.5c). This is the consequence of the gradual adoption of low-emission stables below a maximum permitted loss of 50 kg NH_3-N, enabling maintenance of stocking rate and milk production. Maintenance of production, however, does not translate in maintenance of labour income (Figure 5.5a), as costs of low-emission stables are higher. One other measure taken to comply with restricted volatilisation losses is adoption of day-and-night grazing systems, at the expense of zero grazing systems. Tightening the restriction on volatilisation to values below 40 kg NH_3-N has a larger impact, as extensification beyond this point proceeds at a higher rate (Figures 5.5b and c). Extensification of milk production in the range of permitted NH_3-N loss between 65 and 30 kg is expressed in reductions in stocking rate, slurry use in N-fertilisation of grassland (Figure 5.5b), effective N application rate per ha grassland (Figure 5.5b) and regional milk production (Figure 5.5c). Tightening the restriction on NH_3-N loss from 25 to 19 kg ha^{-1},

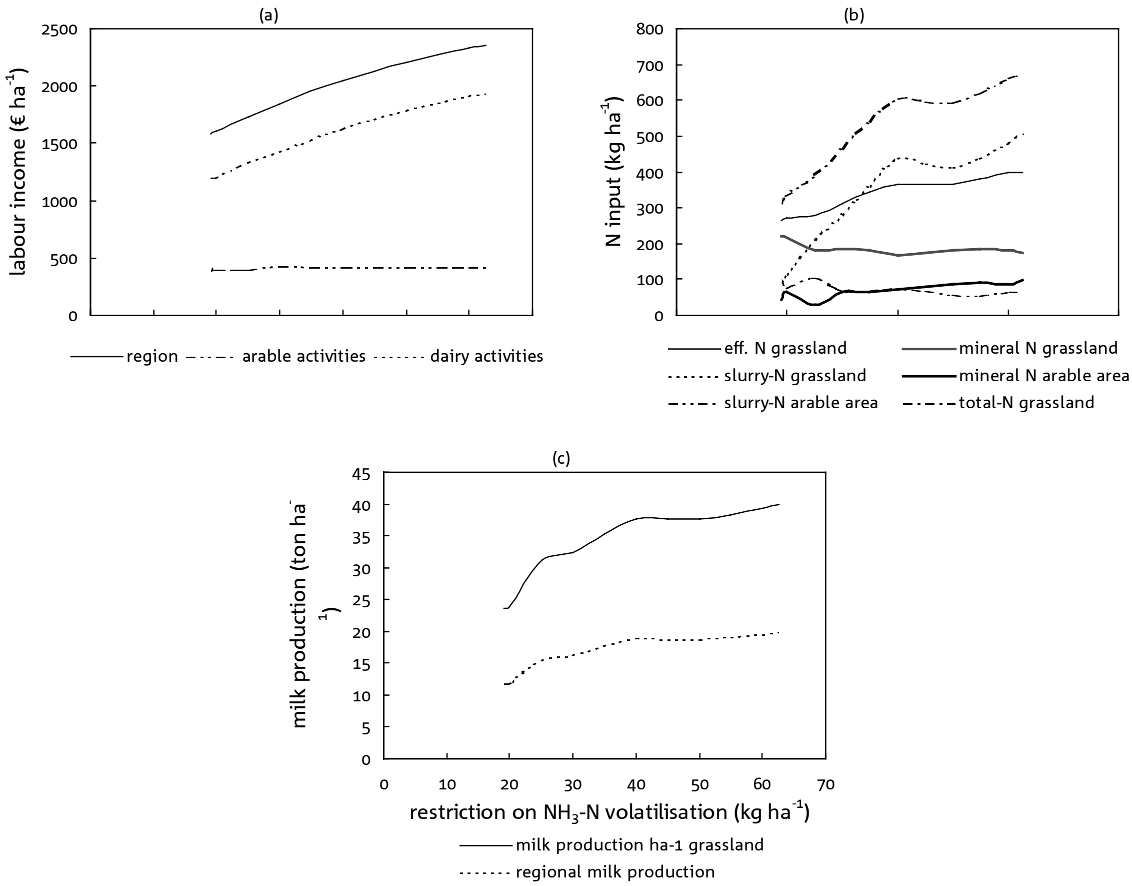

Figure 5.5. *Changes induced in mixed farming, maximising labour income while gradually tightening the restriction on NH_3-N volatilisation at a maximum leaching loss of 34 kg N ha^{-1}: (a) regional labour income and labour income resulting from dairy and arable activities (in € per regional ha), (b) N fertilisation of grassland and arable crops (kg N per ha grassland and kg N per ha arable crops, respectively), and (c) milk production (ton per regional ha and per ha grassland). In all graphs, the x-axis denotes NH_3-N volatilisation in kg ha^{-1}.*

induces a sharp decline in regional milk production (Figure 5.5c). This is caused by a strong, albeit partial substitution of low-emission stables combined with day-grazing by standard stables combined with day-and-night grazing. As a result, less cattle can be kept in the region and less milk is produced. Apparently, from the perspective of regional income, it has become unattractive to keep cattle in expensive low-emission stables.

If NH_3-N volatilisation is restricted to 19 kg ha^{-1}, with NO_3-N leaching unrestricted, half of the area is under grassland and half is under arable crops.

Maximum regional labour income is € 1 731 ha^{-1} and associated NO_3-N loss 61 kg ha^{-1}. Leys are combined with 1:8 crops silage maize, winter wheat, ware potato and sugar beet. Winter wheat is used as feed in dairy farming and partly harvested as feed grain and partly as cereal silage. With the exception of sugar beet, arable crops are cultivated at economically optimal yields. Sugar beet, a crop inducing NH_3-N emission (see Table 3.10), is cultivated at the lowest yield defined, apparently to save 'NH_3-N emission rights' for more profitable milk production activities. With unrestricted leaching loss and as under maximum regional income, arable crops in mixed farming systems are used to 'dump' large amounts of cattle slurry, averaging 245 kg total-N ha^{-1} arable crops and corresponding to 75% of the amount produced. Consequently, leaching loss under the arable crop area is as high as 110 kg N ha^{-1}.

Stocking rate in the region is 1.94 dairy cows ha^{-1} and regional milk production 15 485 kg ha^{-1}. All cattle are kept in low-emission stables, and 90% is in grazing systems. Both measures fit in a strategy to comply with restricted volatilisation losses. Effective N-application rate on grassland is 275 kg N ha^{-1}. Leaching under grassland is only 11 kg NO_3-N ha^{-1} grassland, compensating high leaching losses under arable crops. Low leaching loss under grassland is feasible, because grassland is moderately fertilised and because 70% of cattle are kept in day grazing systems, restricting high N concentrations in urine patches.

Restricting NO_3-N leaching losses will primarily affect arable crop production, because arable crops show relatively higher leaching losses than grassland. Tightening the NO_3-N restriction to 50 kg ha^{-1}, mineral-N supply to arable crops is reduced from 40 to 20 kg N ha^{-1} arable crops and slurry-N supply from 251 to 200 kg (Figure 5.6b). As a consequence, all arable crops are cultivated at economically sub-optimal yields. Leaching loss under arable crops, however, is still as high as 85 kg NO_3-N ha^{-1}, which is related to the still considerable use of slurry in N fertilisation of arable crops. Had slurry-N supply to arable crops been further reduced, arable crops could have been cultivated at higher yields. This strategy initially is not selected, illustrating that, from the perspective of regional income, it is more attractive to maintain milk production in the region as high as possible (Figure 5.6c) by keeping all cattle in low-emission stables and accepting the cultivation of arable crops at lower yields. A similar result was found for specialised farming systems. Tightening the restriction on NO_3-N leaching from 50 to 40 kg, however, the strategy to drastically reduce slurry-N supply to arable crops is yet selected (Figure 5.6b). While leaching under the

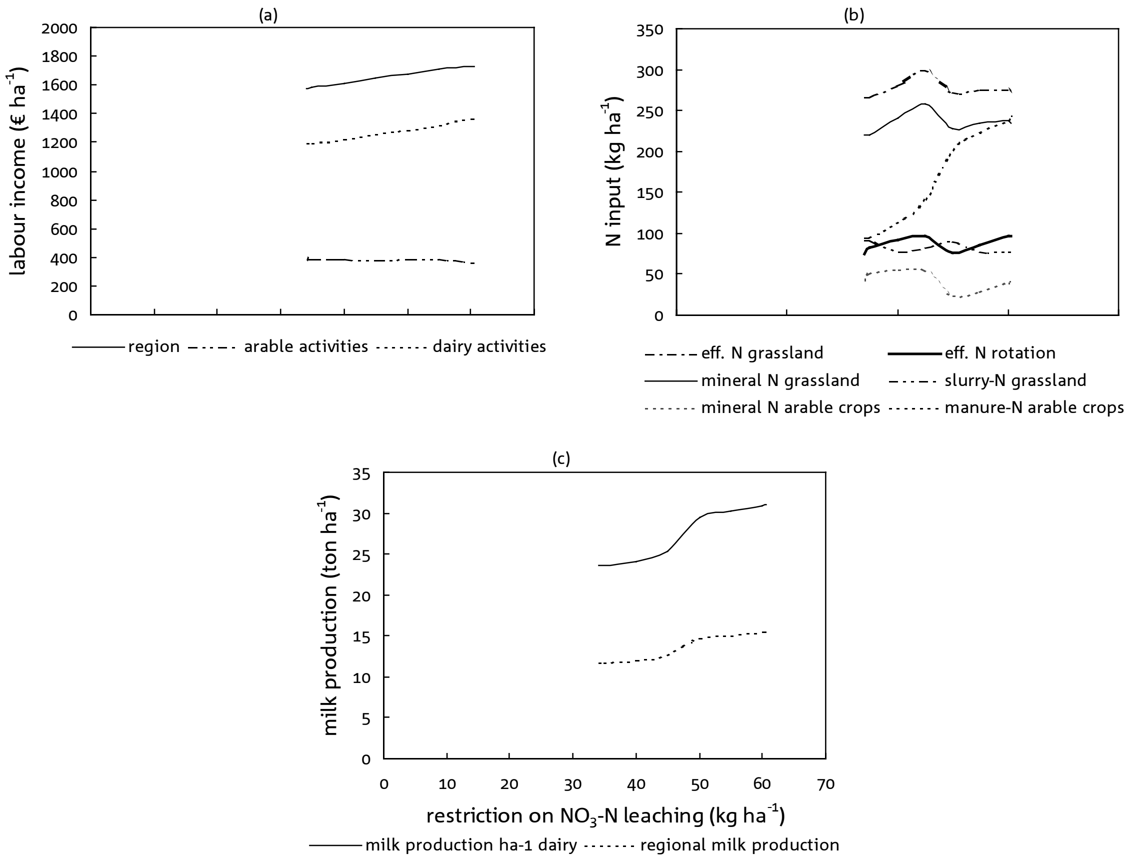

Figure 5.6. Changes induced in mixed farming, maximising labour income while gradually tightening the restriction on NO_3-N leaching at a maximum volatilisation loss of 19 kg N ha^{-1}: (a) regional labour income and labour income resulting from dairy and arable activities (in € per regional ha), (b) N fertilisation of grassland and arable crops (kg N per ha grassland and kg N per ha arable crops, respectively), and (c) milk production (ton per regional ha and per ha grassland). In all graphs, the x-axis denotes NO_3-N leaching in kg ha^{-1}.

arable crop area decreases from 85 to 62 kg N ha^{-1}, mineral N and effective N supply to arable crops increase by 33 and 15 kg N ha^{-1}, respectively (Figure 5.6b). Hence, crops are on average cultivated at higher yields. In the same tightening-step, maize is replaced by onion. To partly compensate for the loss of this fodder crop, mineral and effective N application to grassland are both increased. Because of reduced manure application opportunities, apparently, keeping cattle in low-emission stables has become less attractive, as 60% of the cattle is housed in standard stables, further limiting stocking rate. Regional

Table 5.18. Agronomic and MINAS nutrient balances of the mixed farming system, maximising regional labour income *with restrictions on N-losses. All data in kg* ha^{-1}.

	agronomic		MINAS	
	N	P	N	P
Inputs				
deposition	30	1	-	-
mineral fertiliser	131	7	131	-
concentrates	105	21	105	21
Total inputs	266	29	236	21
Outputs				
milk	62	11	62	11
crops	46	9	65	11
animals	8	2	8	2
'unavoidable' N-loss	-	-	27	-
Total outputs	117	22	162	24
Surpluses				
Agronomic surplus	149	7	-	-
MINAS surplus	-	-	74	-2
Levy-free surplus	-	-	140	9

milk production decreases from 14 750 to 12 000 kg (Figure 5.6c). Further tightening the leaching restriction to 34 kg N ha^{-1} induces a further, albeit limited extensification of the farming system.

In all situations in Figures 5.5 and 5.6, MINAS N and P surpluses do not exceed the levy-free surpluses. Agronomic and MINAS nutrient balances of the mixed farming system complying with the policy standards are given in Table 5.18.

5.4 Discussion

5.4.1 Modelled effects of manure policy regulations on labour income and N-losses

In all model calculations for the arable and pig sectors, MINAS surpluses are lower than levy-free surpluses. Hence, labour income and N-losses in these sectors are not restricted by the MINAS system. The manure contract system does limit labour income and N-losses in the arable and pig sectors: in the absence of the system - provided N-losses are unrestricted -, more pigs can be been held in the region and more manure-N used in fertilisation of arable crops, increasing labour income and N-losses in both sectors. However, limiting effects of the manure contract system in the real world are likely to be small, as, supposedly, absence of the system would not result in a large increase in the manure acceptance rate at arable farms. From this perspective, limiting effects of the manure contract system on labour income and N-losses in the arable and pig sector are small.

In the dairy sector, the manure contract system serves as a strong stimulus to realise MINAS surpluses not exceeding the levy-free surpluses, as that allows more manure production and application within the sector (see Section 5.1). Hence, in neither of the calculations for the dairy sector, MINAS surpluses exceeded levy-free surpluses. In all situations, the MINAS P-surplus equals the levy-free surplus, and in contrast to the arable and pig sector, MINAS indirectly restricts (i.e. via the manure contract system) labour income and N-losses. In the absence of the manure contract system, MINAS surpluses exceeding the levy-free surpluses would not affect permitted manure production and application within the dairy sector, hence its effect would be much less far-reaching. To illustrate, without the manure contract system, indeed a MINAS P-levy is paid and maximum labour income in the dairy sector increases from € 1 858 (Table 5.8) to € 2 089 per ha. If dairy farming is combined with arable cropping in a specialised farming system, the manure contract system additionally limits labour income and N-losses in the dairy sector, because it limits manure application opportunities in the arable sector. However, as noted above, in reality, the effect of the manure contract system on manure acceptance rate in the arable sector is presumably small.

MINAS and the manure contract system in mixed farming systems act in a similar manner as in the specialised dairy sector, the manure contract system serving as a strong stimulus to realise MINAS surpluses that do not exceed the levy-free surpluses. Hence, in mixed farming systems under unrestricted N-losses, MINAS N and P surpluses equal levy-free surpluses. MINAS in the mixed farming system therefore restricts labour income and N-losses indirectly via the manure contract system.

MINAS P surplus equals the levy-free surplus in all situations in the dairy sector. The only input in the MINAS P balance of the dairy sector is P in imported feeds (e.g. Tables 5.12 and 5.14). This suggests that, from an economic perspective, it is more attractive to import the maximum quantity of feeds as allowed by the MINAS P balance into the dairy sector, rather than producing this feed within the dairy sector, as is illustrated in the following example. When maximising labour income in the dairy sector and fixing milk production at 18 000 kg ha^{-1}, this quantity is produced importing the maximum quantity of concentrates, i.e. such that the MINAS P surplus equals the levy-free surplus. Associated labour income is € 1 704 ha^{-1}. An equal amount of milk can also be produced whilst realising a MINAS P surplus below the levy-free P surplus, but is at the expense of labour income. For example, adding the restriction that the MINAS P surplus should be 5 kg ha^{-1} below the levy-free surplus, reduces labour income by 5% and is associated with reduced concentrate input and increased N application rate in grassland. Increased N-input in grassland increases grassland productivity, compensating the reduced concentrate input.

5.4.2 Differences in regional labour income between specialised and mixed farming systems

Maximum labour income per ha in mixed farming systems is higher than in specialised farming systems, both with and without restrictions on N-losses. The difference in labour income between mixed and specialised farming is € 730 ha^{-1} when N-losses are unrestricted and € 320 ha^{-1} when N-losses are restricted. These values represent 45 and 25%, respectively, of maximum labour income in specialised farming systems. Higher regional labour income in mixed farming systems is explained by higher yields per ha of the arable crops and notably by higher milk production.

With unrestricted N-losses, milk production in the mixed farming system is higher because of two reasons. Firstly, the impact of the MINAS system in specialised farming systems is different from that in mixed farming systems. In specialised farming systems, MINAS surpluses in the arable sector are always appreciably lower than levy-free surpluses. The non-restrictive character of the MINAS system in that sector provides scope for additional production in the region, which, however, can not be utilised in specialised farming systems. This is different in the mixed farming system: as only one combined MINAS balance is calculated, the scope for additional production as provided by the non-restrictive character of MINAS in arable cropping can entirely be utilised and is allocated to the most profitable activity, dairy farming. Hence, if the specialised dairy and arable sector would *ceteris paribus* join their separate MINAS balances to one combined MINAS balance, the difference in maximum labour income between the specialised and mixed farming system would decrease from € 730 ha^{-1} to € 570 ha^{-1}, entirely attributable to an increase in milk production in the specialised farming system.

Secondly, regional manure production in the mixed farming system under the manure contract system can attain a much higher value than in the specialised farming system. This is explained by the manure contract system not imposing any limit on manure-N use in arable crops in the mixed farming system, as long as MINAS surpluses do not exceed levy-free surpluses. In contrast, in specialised farming systems, the system limits manure-N use in the arable sector to 85 kg N ha^{-1}, as it is assumed that arable farmers conclude manure contracts for only half the permitted amount. Consequently, milk production in the specialised dairy sector is restricted by MINAS at lower milk production. Hence, if the specialised arable sector would *ceteris paribus* conclude manure contracts up to, for example, the legal maximum (170 kg N ha^{-1}), the difference in maximum labour between the specialised and mixed farming system would decrease from € 730 ha^{-1} to € 475 ha^{-1}.

When the specialised dairy and arable sector join their MINAS balances, there exists no longer any limit on manure-N use in arable crops - as in the mixed farming system - provided MINAS surpluses do not exceed levy-free surpluses. Assuming that the arable sector is indeed prepared to accept large amounts of manure from the dairy sector, the difference in maximum labour between the specialised and mixed farming system is only € 118 ha^{-1}. The difference is largely explained by higher yields per ha arable crops in the mixed farming system.

Also with restricted N-losses, milk production in the mixed farming system is higher. This relates to the way the restrictions are imposed, i.e. on individual economic units. For specialised farming systems, this implies that restrictions are imposed separately on the arable, pig and dairy sector. For mixed farming systems, restrictions are imposed on the entire farming system, as that corresponds to the economic unit. As a consequence, in mixed farming systems, high N-losses in one part of the region may be compensated by low N-losses in another part. Setting restrictions to N-losses to parts of the region in specialised farming systems reduces the 'window of opportunities' available to the MGLP model, resulting in lower maximum regional labour income.

Higher labour income in mixed farming systems, as mainly derived from higher milk production, follows from institutional considerations, notably (1) the impact of manure policy regulations and (2) the use of manure-N in crop fertilisation in mixed farming systems in excess of 85 kg N ha^{-1}. The approach is justified here as being compatible with agri-environmental policies, such as MINAS and the manure contract system, that are oriented towards the economic unit. In addition, the approach used is presumably compatible with the mode of thinking of a (group of) farmer(s). The limit set to maximum manure-N use in the arable sector, as part of a specialised farming system, is in fact based on specialised arable farmers' viewpoints. For mixed farming systems, it is implicitly assumed that a (group of) farmer(s), aiming at high labour income, will be inclined to use more manure-N in crop fertilisation.

5.4.3 Manure policy regulations and N emissions

In this study "attaining the objectives specified in the Nitrate Directive" has been simplified to "reducing NO_3-N loss to a value below 34 kg ha^{-1}". NO_3-N loss in optimisations with unrestricted N-losses exceed this standard in both the arable and dairy sector, as well as in specialised and mixed farming systems. In addition, Figures 5.1 and 5.3 show that the majority of farming systems underlying the solution areas for specialised and mixed farming does not meet the environmental standards defined in this study. The more profitable farming systems coincide with farming systems that show the higher N-emissions.

One of the objectives of the Nitrate Directive is to maintain NO_3-N concentrations in groundwaters suitable for drinking water below 11.3 mg per litre. This objective is, however, less relevant for the clayey areas in the Netherlands, as the precipitation surplus in these areas is largely discharged in surface waters. Therefore, in the clayey areas a more relevant objective is the reduction of the NO_3 load from the agriculture sector to surface waters. Such objective in quantitative terms is absent in the Nitrate Directive, but has been formulated in Anonymous (1989): mean N emission from agriculture to surface waters should decrease by more than 50%, with 1985 as reference year. This objective is part of the Rhine Action Programme and the North Sea Action Programme.

MINAS in this study does not affect the arable sector. Moreover, MINAS allows the application of manure-N in almost double the quantities considered here, without exceeding the levy-free surpluses, which would have been associated with larger NO_3-N leaching losses. Hence, MINAS still leaves ample room for the inefficient use of N in the arable sector, associated with large N-losses (this study; van Dijk & van der Schoot, 1999). Therefore, the contribution of MINAS to reducing NO_3 load from the arable sector to surface waters by at least 50% - with 1985 as reference year - can be questioned for three reasons. Firstly, in 1999/2000, that is before the introduction of MINAS, 50-60% of a representative sample of arable farms realised MINAS N surpluses below the current levy-free surplus (de Hoop, 2002). Hence, MINAS leaves NO_3-N emission at 50-60% of arable farms unaffected. Secondly, 40-50% of arable farms realising MINAS surpluses exceeding the levy-free surpluses are farms that use considerable amounts of manure (de Hoop, 2002). In response to MINAS, these farms are likely to reduce their manure input, associated with reductions in NO_3-N loss at these farms. However, it seems not unthinkable that part of the 50-60% arable farms realising MINAS surpluses below the levy-free surpluses increase their manure-N input, tempted by higher revenues from manure use and resulting in increased NO_3-N loss at these farms. Accordingly, the MINAS system could result in a levelling of MINAS surpluses at arable farms, with a limited net effect on NO_3 load to surface waters. Thirdly, N surpluses at arable farms have hardly changed since the mid 1980s, and in some regions even showed an increase since the early 1990s, due to increased manure-N use, since that became an additional income source (de Hoop, 2002). The increase in manure-N use in the early 1990s is likely associated with an increase in NO_3 load since 1985. This analysis shows that future trends in NO_3 load from the arable sector will strongly be determined by developments in the 'manure market' and by arable farmers' responses to these developments. A crucial factor is whether arable farmers are paid for the use of manure at their farms (the current situation) or have to pay for manure.

In contrast to the arable sector, the dairy sector is limited by the MINAS system. Nevertheless, the selected dairy farming system optimised for labour income is very intensive in terms of production per ha, which is combined with zero-grazing. Such intensive dairy farming systems currently cover only a part of the dairy farming systems in the Netherlands (see e.g. Reijneveld *et al.*, 2000). In the near future, with reduced EU market price support for dairy products and more open international markets, economically-efficient dairy farming becomes increasingly important and Dutch dairy farming might well develop in the direction of zero-grazing (see Chapter 7). Bearing this in mind, the analysis in this chapter shows that it is possible, within the restrictions imposed by manure policies, to realise a high milk production, while attainment of environmental goals is not ensured. There is a movement in Dutch society opposing a development of the dairy sector in the direction of zero-grazing, as grazing contributes to the positive image of the dairy sector and to health and welfare of cattle. Nutrient emissions and labour income in the dairy sector in less intensive diary farming systems under grazing will be addressed in the next chapter.

5.4.4 Organic N balances

The modelling technique used in this study follows a static approach. Input-output coefficients underlying the model are based on current quality of natural resources. To maintain validity of input-output coefficients, this quality should not change too much. One of the important indicators for this quality in agricultural systems is organic matter content of soils, determining mineralisation rates. To ensure that current mineralisation rates are about maintained, organic N balances are constrained in the model by an upper and a lower bound. Organic N balances are calculated as the sum of organic N balances of the selected milk, roughage and crop production activities plus the organic N applied with manure. Bounds for grassland and arable crops are about 1% of organic N in soils under grassland and arable crops, respectively (see Chapter 4).

Upper and lower bound for crop rotations in specialised arable cropping systems are set to +50 and -50 kg ha^{-1}, respectively. In optimisations performed in this chapter involving the arable sector, selected crop production activities show negative organic N balances, that are only partially compensated by organic N inputs via manure. As a consequence, in all optimum crop rotations presented above, organic N balances are negative and often close to the lower bound. Hence, organic soil-N reserves in the arable sector are depleted, albeit at a low rate. The rate of depletion of organic soil-N reserves can be reduced in the model by increasing the lower bound to a value closer to zero. This limits the degrees of freedom for the MGLP model and forces incorporation into the rotation of arable crops with less negative or positive organic N balances (e.g. white cabbage) or adoption of techniques to increase organic N inputs (e.g. application of solid pig manure). This goes at the expense of labour income. For example, if the lower bound is changed from -50 to -20, maximum labour income in the arable sector without restrictions on N-losses is € 850 (compared to € 926 in the original model formulation; Table 5.2). The tightened constraint on the organic N balance of the crop rotation is complied with by increasing solid pig manure input and by leaving wheat straw in the field. The equivalent optimisation with restrictions on N-losses, yields a maximum labour income of € 660 (compared to € 818 in the original model formulation; Table 5.2). Hence, the difference between maximum labour income and labour income at restricted N-losses is much larger when the lower bound is tightened to -20. If N-losses are restricted, the MGLP model has less 'freedom' to comply with the constraint on organic N by manipulating manure input, as production and application of manure increases N-losses. Thus, the model is forced to select less profitable cropping activities with positive organic N balances, such as the cultivation of white cabbage and corn-cob-mix.

The issue of depleting organic soil-N reserves does not play a role in specialised dairy farming. On the contrary, all organic N balances of dairy farming systems are at their upper bound. This implies that in the long run mineralisation in the dairy sector will increase.

Land use in specialised dairy farming systems is a combination of grassland and continuously cropped maize. Upper and lower bounds on net change of the organic N pool are set to +100 and -100 kg ha^{-1} grassland plus +50 and -50 kg ha^{-1} continuously cropped maize. The formulation of the constraint on organic N balances of specialised dairy farming systems implies that more manure-N can be applied as milk, roughage and/or crop production activities show more negative organic N balances. Because organic N balances of production activities for continuously cropped maize (about -100 kg N ha^{-1}) are considerably more negative than those of economically attractive milk and roughage production activities (i.e. at least moderately fertilised), more manure-N can be applied, hence produced, as more continuously cropped maize is selected. Hence, in model terms and from the perspective of labour income, negative organic N balances of continuously cropped maize constitute an advantage over grass. Abolishing this advantage of maize, for example by restricting the maximum permitted accumulation of organic N under maize land from +50 to zero kg ha^{-1}, hardly affects the configuration of the dairy sector, but reduces maximum labour income to € 1 765 (compared to € 1 858 in original model formulation; Table 5.8), due to reduced opportunities to apply manure. The area allocated to maize is about maintained, because one other major advantage of maize, i.e. its lower N-content, is still in effect.

Upper and lower bounds on net change of the organic N pool in mixed farming systems are calculated in a similar way as in specialised dairy farming systems, i.e. set to +100 and -100 kg ha^{-1} grassland plus +50 and -50 kg ha^{-1} arable crops. Organic N balances of mixed farming systems are positive, but not at their upper bound.

The analysis presented here shows that the selection of upper and lower bounds to organic N balances greatly affects model results. For a more detailed approach of organic matter dynamics in agricultural systems, process-based models are required (Hengsdijk & van Ittersum, 2002).

5.5 Conclusions

- Manure policy regulations foreseen for the year 2003 allow farming systems characterised by the production of large quantities of manure-N and subsequent inefficient use of that N in maize and arable crops.

- Maximum labour income in the regionally mixed farming system is much higher than in the regionally specialised farming system. Higher labour income arises from a different impact of manure policy regulations on the mixed farming system, allowing a much higher milk production than in the specialised farming system.

- Attaining the policy standard for NO_3-N leaching in regional dairy farming requires the maize area to remain below a threshold value and/or limited use of manure-N in fertilisation of that crop.

- Attaining the policy standard for NO_3-N leaching in regional arable cropping requires cultivation of crops at economically sub-optimal yield levels, the use of catch crops after slurry applications in autumn and matching applied quantities with N uptake capacity of catch crops.

- Attaining the policy standard for NO_3-N leaching in regional mixed farming allows cultivation of arable crops at economically optimal yield levels, because associated high leaching loss under these crops is compensated by low leaching loss under grassland.

- MINAS and the manure contract system are not targeted towards reducing NH_3-N volatilisation. To attain the policy standard for NH_3-N volatilisation additional measures need to be taken, including limits to animal density, adoption of low-emissions systems and/or adoption of grazing systems.

- Simultaneously attaining the policy standards for NO_3-N leaching and NH_3-N volatilisation is associated with considerable reductions (10-35%) in labour income.

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CHAPTER 6

Efficacy of adjustments to the design of Dutch manure policy regulations in reducing excess NO_3-N emission

6.1 Introduction

In the calculations reported in Chapter 5, labour income was maximised for specialised and mixed farming systems under the current design of MINAS and the manure contract system, using the modelling framework described in Chapters 3 and 4. As all selected farming systems complied with Dutch manure policy regulations, model results could be used to evaluate the efficacy of these regulations in avoiding excess nutrient emissions. It was assumed that excess nutrient emissions were avoided if NO_3-N leaching did not exceed 34 kg ha^{-1} and NH_3-N volatilisation did not exceed 19 kg ha^{-1}. Results of the MGLP model showed that emissions from farming systems optimised for labour income did not meet these standards, neither at sector nor at regional scale and neither in specialised nor in mixed farming systems. These results suggest that MINAS and the manure contract system must be adjusted to reduce N-emissions to the desired level.

MINAS and the manure contract system were not specifically aimed at reducing NH_3-N emission, but both systems have an emission-reducing effect, as they limit manure-N production. However, to comply with the policy standard for NH_3-N emission, additional measures are required. This chapter focuses on design of MINAS and the manure contract system only in relation to NO_3-N leaching.

Nitrate Directive regulations specify that the amount of manure that can be applied to farmland should not exceed 170 kg N per ha arable land plus 250 kg N per ha grassland[1]. Current Dutch manure policy permits dairy and mixed farms to deviate from this regulation, by allowing these farms to produce and apply manure in excess of the stipulated rates, provided their MINAS surpluses do not exceed levy-free surpluses (‘flexible interpretation’ of Nitrate Directive; see Section 5.1.2). Hence, manure production at such farms can be higher than under a strict compliance regime, and this contributes to N-emissions. An optional adjustment to the manure contract system therefore is strict, farm-scale implementation of the regulations in the Nitrate Directive, implying that manure in excess of 170 kg N per ha arable land plus 250 kg N per ha grassland is either not produced or transferred to ‘consumers’ of manure, irrespective of MINAS surpluses at manure-producing farms.

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[1] This is under the assumption that the derogation request will be granted.

The MINAS system will only affect properties of farming systems if it is changed in such a way that the gap between calculated MINAS surpluses in Chapter 5 and levy-free surpluses is at least bridged. Beyond that point, optimum configuration of the farming system can either remain unchanged - hence as in Chapter 5, but accepting payment of MINAS levies - or adapted so as to avoid paying levies. In the first case, only labour income is affected, but not NO_3-N leaching. In the second case, both labour income and NO_3-N leaching are affected. The gap between calculated MINAS surpluses and levy-free surpluses can be bridged in several ways, e.g. by (1) reducing levy-free surpluses, (2) reducing default values used to quantify nutrient removal in arable crops, (3) reducing the 'unavoidable' N loss term in animal production and (4) inclusion of P-inputs via mineral fertiliser. Options (1), (2) and (3) affect the gap in a similar way: reducing the levy-free surplus by e.g. 10 kg ha^{-1} has the same effect on the gap as reducing nutrient removal in arable crops or 'unavoidable' N loss by 10 kg ha^{-1}. Hence, investigating each of these options is superfluous. Therefore, only the first and the fourth option are considered.

The aim of this chapter is to assess the efficacy of adjustments to the design of MINAS and the manure contract system in reducing NO_3-N leaching, and to quantify their effects on labour income. Research questions are:

(1) what are effective adjustments to the design of MINAS and the manure contract system to restrict NO_3-N leaching to a level below 34 kg ha^{-1}?

(2) what are effects of these adjustments on labour income in specialised and mixed farming systems?

(3) what are effects of these adjustments on optimal configuration of farming systems?

6.2 Methodology

Based on the properties of the farming systems in Chapter 5 (further referred to as reference farming systems), possible adjustments to the design of MINAS and the manure contract system are discussed. Promising adjustments are implemented in the MGLP model and effects on nutrient losses and labour income quantified while maximising labour income. Guiding principle in all optimisations is that, when maximising labour income, NO_3-N leaching should not exceed the policy standard of 34 kg N ha^{-1} without the need to use a restriction in the MGLP model. The procedure is followed first at sector level for the land-based arable and dairy sectors. Determination of maximum labour income and NO_3-N emission in each sector under alternative designs of MINAS and the manure contract system is similar to the procedure followed in Chapter 5, hence involving two optimisations. In the first optimisation, maximum sectoral labour income is calculated. Subsequently, regional labour income is maximised, with maximum sectoral labour income from the first optimisation serving as a restriction.

If adjustments sufficiently reduce NO_3-N leaching at sector scale, effects of these adjustments are quantified at the regional scale, for specialised and mixed farming systems separately.

6.3 Results

6.3.1 Arable sector

When maximising labour income in the arable sector under current design of MINAS and the manure contract system, NO_3-N loss was 58 kg ha^{-1} (reference arable sector; see Subsection 5.3.1). Leaching resulted from crops being cultivated at economically optimal yields and from autumn application of pig slurry above N-uptake capacity of catch crops. MINAS N and P surpluses were 14 and -9 kg ha^{-1}, respectively. As MINAS surpluses were lower than levy-free surpluses (100 kg N and 9 kg P ha^{-1}), labour income and N losses in the reference arable sector were not restricted by the MINAS system.

MINAS nitrogen

To bridge the gap between current MINAS N surplus and levy-free N surplus, the latter has to be reduced to a value below 14, before labour income and NO_3-N loss in the arable sector are affected. To attain the policy standard for NO_3-N leaching, the levy-free N-surplus should be reduced to -60 (Figure 6.1). In reducing the levy-free N surplus for arable land from 14 to -60, the configuration of the arable sector is adapted in such a way that the MINAS N surplus equals the levy free surplus and hence paying a levy is avoided. Design of the crop rotation equals that in the reference arable sector, but crops are partially cultivated at economically sub-optimal yields. Pig manure input is reduced from 85 to 66 kg N ha^{-1}. Labour income in the arable sector is € 820, i.e. 90% of that in the reference situation. If the levy-free N surplus is further reduced to values below -60 kg ha^{-1}, the MINAS N surplus increasingly exceeds the levy-free N surplus and a levy is paid.

Note that the MINAS N balance underestimates inputs by 30 kg ha^{-1} (due to exclusion of N in deposition) and overestimates outputs by 55 kg (due to high default values used to quantify nutrient removal in crops). Hence, a MINAS N surplus of -60 kg ha^{-1} corresponds with an agronomic N surplus of 25 kg ha^{-1}. Total N loss exceeds this agronomic N surplus, i.e. organic soil-N reserves are depleted.

MINAS phosphorus

Reducing the levy-free P-surplus is not an appropriate measure to reduce NO_3-N loss in the arable sector, as P-input and agronomic P surplus in the reference arable sector are about at their minimum values (see Table 5.3). These minimum values are determined by a constraint in the MGLP model, requiring P-outputs in crop products to be at least compensated by P-inputs to maintain

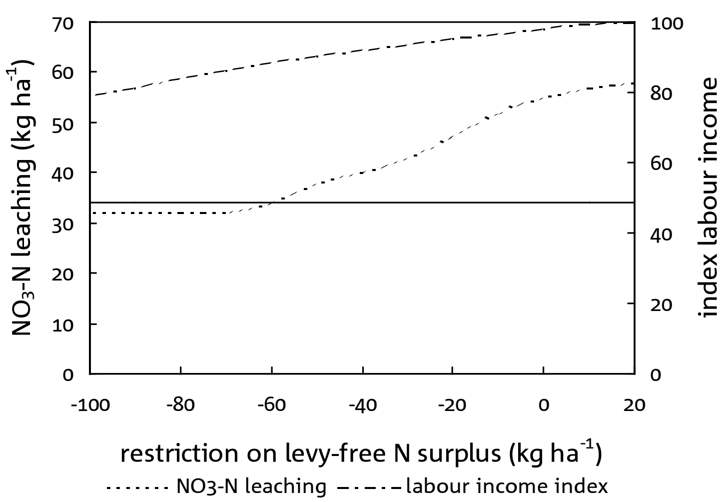

Figure 6.1. *Relationship between levy-free N surplus, NO_3-N leaching and labour income index in the arable sector.*

P-status of the soil (Chapter 4). Hence, irrespective of the levy-free P surplus and of the magnitude of the levy per unit surplus, P-input is maintained at its original level and design of the arable sector remains unchanged. P-input can in principle be as mineral fertiliser or as manure. When maximising labour income in the arable sector, the MGLP model will always maximise P-input via manure, because manure use constitutes an income source. Maximum manure-P-input per ha is the amount associated with 85 kg manure-N.

The configuration of the reference arable sector is unaffected when including P in mineral fertiliser in the MINAS balance: even with mineral P in the MINAS balance, MINAS P-surplus is well below the levy-free P surplus (Table 5.3).

6.3.2 Dairy sector

When maximising labour income in the dairy sector, NO_3-N loss was 48 kg ha^{-1} (reference dairy sector; see Subsection 5.3.1). Seventy percent of the total leaching loss resulted from maize cultivation and its fertilisation on 26% of the total area. MINAS N and P surpluses were 151 and 9 kg ha^{-1}, respectively. Levy-free surpluses were 159 kg N and 9 kg P ha^{-1}. As the MINAS P-surplus equals the levy-free surplus, MINAS restricted labour income and N-losses.

The gap between actual MINAS surpluses and levy-free surpluses in the reference dairy sector is much smaller than in the reference arable sector. Hence, levy-free surpluses need not be reduced to the same extent as in the arable sector, before affecting labour income and, possibly, N-emissions. When reducing levy-free surpluses in the dairy sector, the MGLP model is more likely to adapt the configuration of the farming system, rather than accept payment of MINAS levies, because the manure contract system in the dairy sector serves as a strong stimulus to realise MINAS surpluses below levy-free surpluses, as that allows more manure production and application within the sector.

MINAS nitrogen

In a first series of optimisations, it is explored to what extent the MINAS N surplus needs to be reduced to comply with the goal for NO_3-N leaching. As the relationship between MINAS N surplus and NO_3-N loss will be different for each of the four grazing systems defined in this study (zero grazing without and

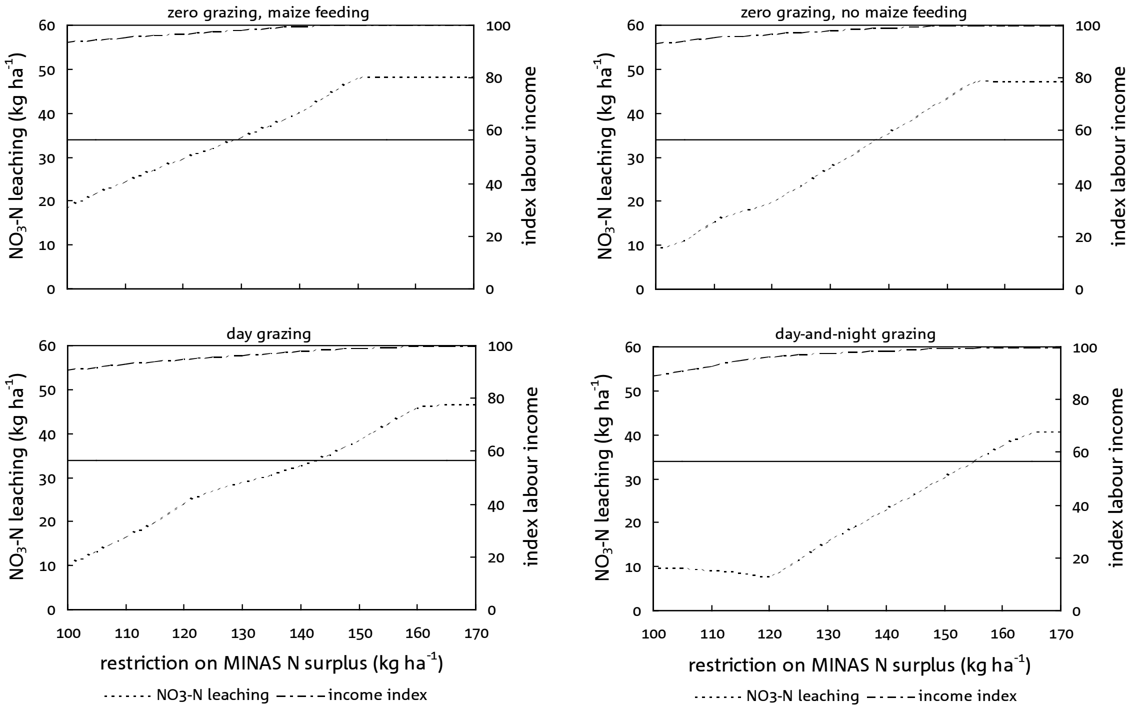

Figure 6.2. *Relationship between MINAS N surplus, NO_3-N leaching and labour income index in the dairy sector under four grazing systems.*

with maize silage in the summer ration of cows, day-grazing, day-and-night grazing; see Chapter 3), it is derived for each grazing system separately (Figure 6.2). In addition to NO_3-N loss, labour income index (percentage of maximum labour income in each grazing system) as a function of MINAS N surplus is plotted.

Maximum MINAS N surplus decreases in the order day-and-night grazing (155 kg ha^{-1}), day-grazing (140 kg ha^{-1}) zero grazing without maize (140 kg N ha^{-1}) and zero grazing with maize (130 kg ha^{-1}). Correspondingly, the gap between these maximum MINAS N surpluses and current levy-free surpluses (not shown in Figure 6.2) increases in the same order, i.e. from about 15 kg N ha^{-1} under the day-and-night grazing system to 35 kg under the zero grazing plus maize system. Changes induced in farming system design by reducing the MINAS N surplus to the level where the standard for NO_3-N leaching is attained are limited. Main change in all grazing systems is a reduction in maize area (e.g. from 26 to 20% in the dairy sector under zero grazing with maize), and hence expansion of the grassland area. Other changes include slight reductions in effective N-application rate on grassland and milk production and a slight increase in concentrate use. For all grazing systems, labour income is hardly affected (Figure 6.2).

Different values for the maximum MINAS N surplus for the four grazing systems are correlated with farming system intensity and NO_3-N loss per ha, which are both affected by grazing system and maize area. Maize area is larger in dairy farming systems with less grazing, and hence is largest in zero grazing systems (20%) and smallest in day-and-night grazing systems (15%). In the model, maize has two advantages compared to grass: (1) inclusion of maize in rations for cows results in lower N-excretion per dairy cow and (2) organic N balances of maize production techniques are considerably more negative than those of grass production techniques. Both advantages allow higher manure production and stocking rates with increasing maize area (see Section 5.4.4). Intensification is further promoted by higher grassland productivity as grazing is less practised. Hence, the dairy sector is intensified in the order day-and-night grazing, day-grazing, zero grazing without maize, zero grazing with maize. This intensification is associated with slightly larger maize areas, showing higher NO_3-N leaching loss per ha than grassland.

If maize areas for each grazing system exceed those underlying Figure 6.2, NO_3-N leaching may exceed 34 kg ha^{-1}, even at restricted maximum MINAS N surpluses. This is for the day grazing system illustrated in Figure 6.3, where NO_3-N leaching increasingly exceeds 34 kg ha^{-1}, as the maize area expands further beyond 20%. These results suggest that maximum MINAS N surplus should be restricted to a lower value, as the maize area is larger (in accordance with the current MINAS system).

To quantify the relationship between maize area and maximum MINAS N surplus to comply with the standard for NO_3-N leaching, additional optimisations were performed, forcing the MGLP model to assign between 10 and 50% of the area to maize (increments 5%) and restricting NO_3-N leaching to 34 kg N ha^{-1} (Figure 6.4) For maize areas below 20% (all grazing systems except day-and-night grazing) or 15% (day-and-night grazing), NO_3-N leaching is lower than 34 kg ha^{-1}. Under those conditions, there is no need to reduce current levy-free surpluses nor to assess maximum MINAS N surpluses. Hence, maize areas below 15-20% are not included in Figure 6.4. MINAS N surpluses in Figure 6.4 for each combination of grazing system and maize area are considered indicative of required maximum MINAS N surpluses to comply with the standard for NO_3-N leaching. The validity of this assumption for e.g. the day grazing system can be tested by reproducing Figure 6.3, however not restricting maximum MINAS N surplus to 140 kg ha^{-1} over the full range of maize areas,

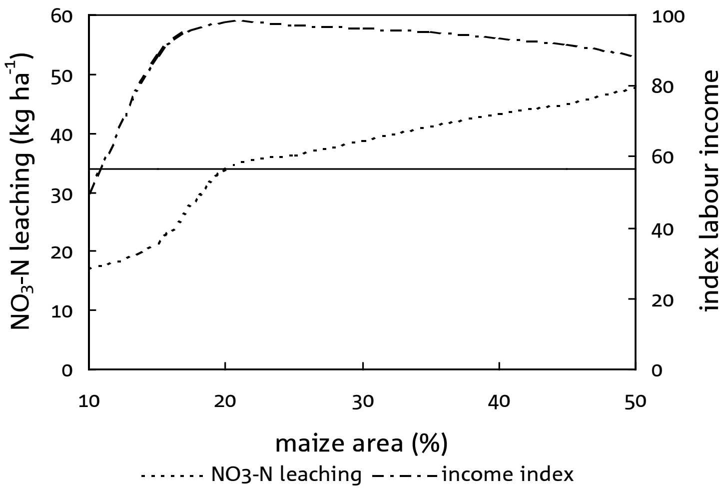

Figure 6.3. *Relationship between maize area, NO_3-N leaching and relative labour income in a day grazing system at a maximum permitted MINAS N surplus of 140 kg ha^{-1} (cf. Figure 6.2).*

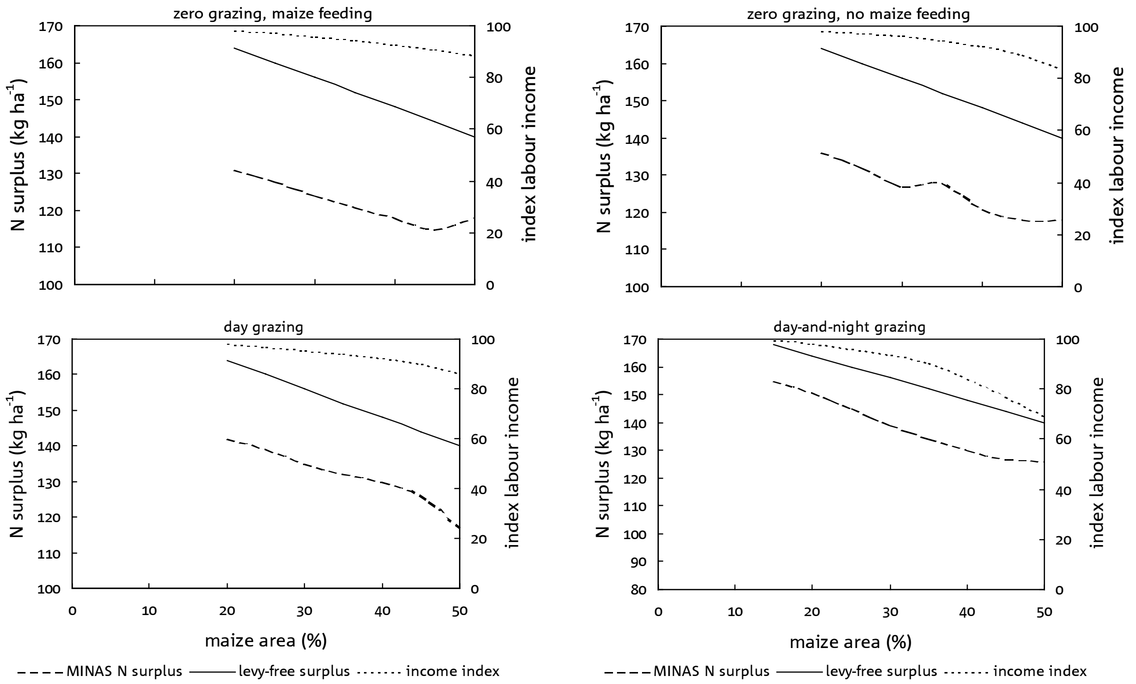

Figure 6.4. *Relationship between maize area, levy-free N surplus, realised MINAS N surplus and relative labour income under current design of MINAS at 34 kg NO_3-N leaching and under four grazing systems.*

but restricting it to maize-area specific values as derived from Figure 6.4 (Figure 6.5). Although NO_3-N leaching still slightly increases with increasing maize area, values are much lower than in Figure 6.3.

The gap between maximum MINAS N surplus to comply with the standard for NO_3-N leaching and current levy-free N surpluses can directly be read from Figure 6.4. This gap for each grazing system is fairly constant over the whole range of maize areas and amounts to about 15, 20, 25 and 30 kg N ha^{-1} under day-and-night grazing, day grazing, zero grazing without maize and zero grazing with maize, respectively.

The current levy-free N surplus is calculated as 180*grassland area plus 100*maize area. Hence, to bridge the gap between maximum MINAS N surplus to comply with the standard for NO_3-N leaching and current levy-free N surplus, the levy-free N surplus per ha grassland and/or the levy-free N surplus per ha maize can be reduced. Modified levy-free surpluses for grassland and maize should be effective in restricting levy-free N surplus at farm level to grazing-system and maize area specific maximum MINAS N surpluses in Figure 6.4, independent of the areas allocated to grass and maize. Such levy-free surpluses are presented in Table 6.1. These levy-free surpluses can also justifiably be applied if maize areas are less than 15-20% (i.e. when reducing the current MINAS N surplus is not necessary as NO_3-N leaching is below 34 kg ha^{-1}), because they then do not restrict labour income (data not shown).

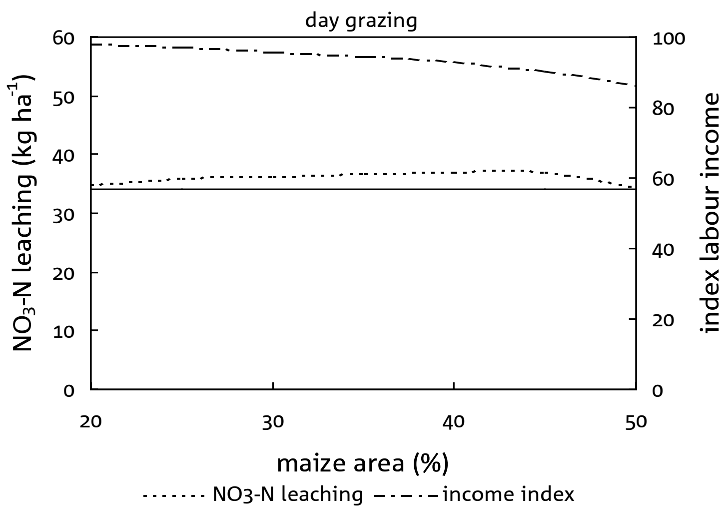

Figure 6.5. Relationship between maize area (x-axis), NO_3-N leaching (left y-axis) and relative labour income (right y-axis) in a day grazing system with MINAS N surpluses restricted to values in Figure 6.4.

Modified levy-free N surpluses for maize and grassland in Table 6.1 are entirely based on maximisations of labour income. Dairy farming systems underlying Figures 6.2 through 6.5 are therefore characterised by high intensity, for example reflected in relatively high milk production per ha and high MINAS N surpluses. Milk production per ha land at commercial dairy farms widely varies, but is usually lower than in the modelled dairy farming systems optimised for labour income. Main reason is that commercial dairy farms are under a milk quota regime, which limits milk production. Lower milk production per ha is generally associated with lower inputs per ha (e.g. Aarts *et al.*, 1988) and lower MINAS N surpluses per ha (Reijneveld *et al.*, 2000). Hence, at lower milk production per ha, the limiting effect of the MINAS system on N losses may disappear in the model, as MINAS N surpluses may attain values below the levy-free N surpluses in Table 6.1. This may result in NO_3-N losses exceeding 34 kg ha^{-1}. To further analyse this possibility, the relationship between milk production per ha and NO_3-N leaching has been derived for a wide range of dairy farming systems, varying in maize area and milk production per ha, using the modified levy-free N surpluses from Table 6.1 (Figure 6.6).

Table 6.1. Current levy-free N surpluses, desired grazing-system and maize area specific MINAS N surplus to comply with the goal for NO_3-N leaching and proposed grazing-system specific levy-free N surpluses per ha maize and per ha grassland.

grazing system	relative area		current levy-free N surplus	desired MINAS N surplus	proposed levy-free N surplus per ha:		resulting levy-free N surplus
	maize	grassland			maize	grassland	
day-and-night	0.15	0.85	168	153	90	165	154
	0.50	0.50	140	125	90	165	128
day	0.20	0.80	164	144	90	155	142
	0.50	0.50	140	120	90	155	123
zero, no maize	0.20	0.80	164	139	90	150	138
	0.50	0.50	140	115	90	150	120
zero, with maize	0.20	0.80	164	134	80	145	132
	0.50	0.50	140	110	80	145	113

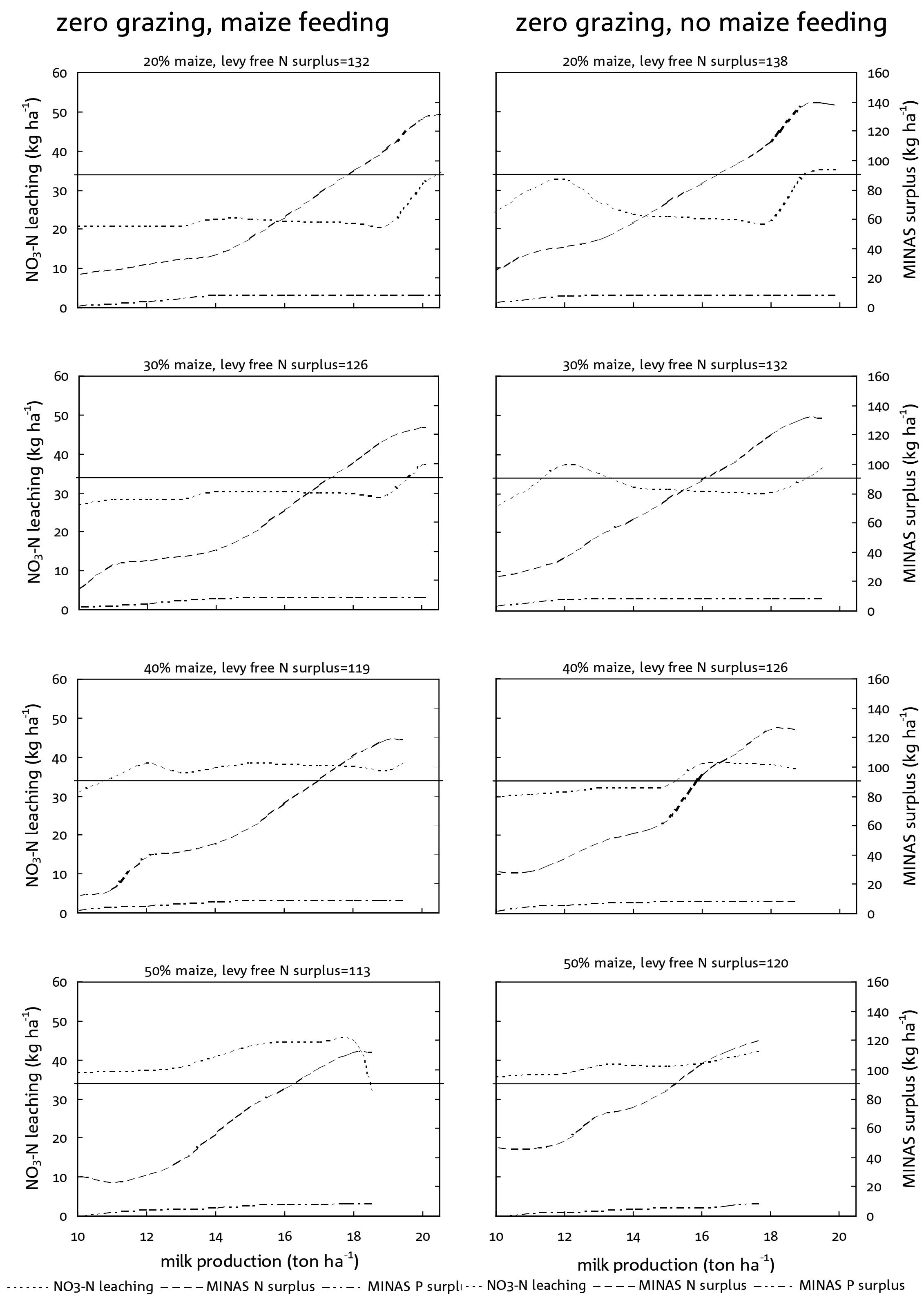

Figure 6.6. *Relationship between milk production level (x-axis), NO_3-N leaching (left y-axis) and MINAS surplus (right y-axis) with 20, 30, 40 and 50% maize and with levy-free N surpluses according to Table 6.1 under four grazing systems.*

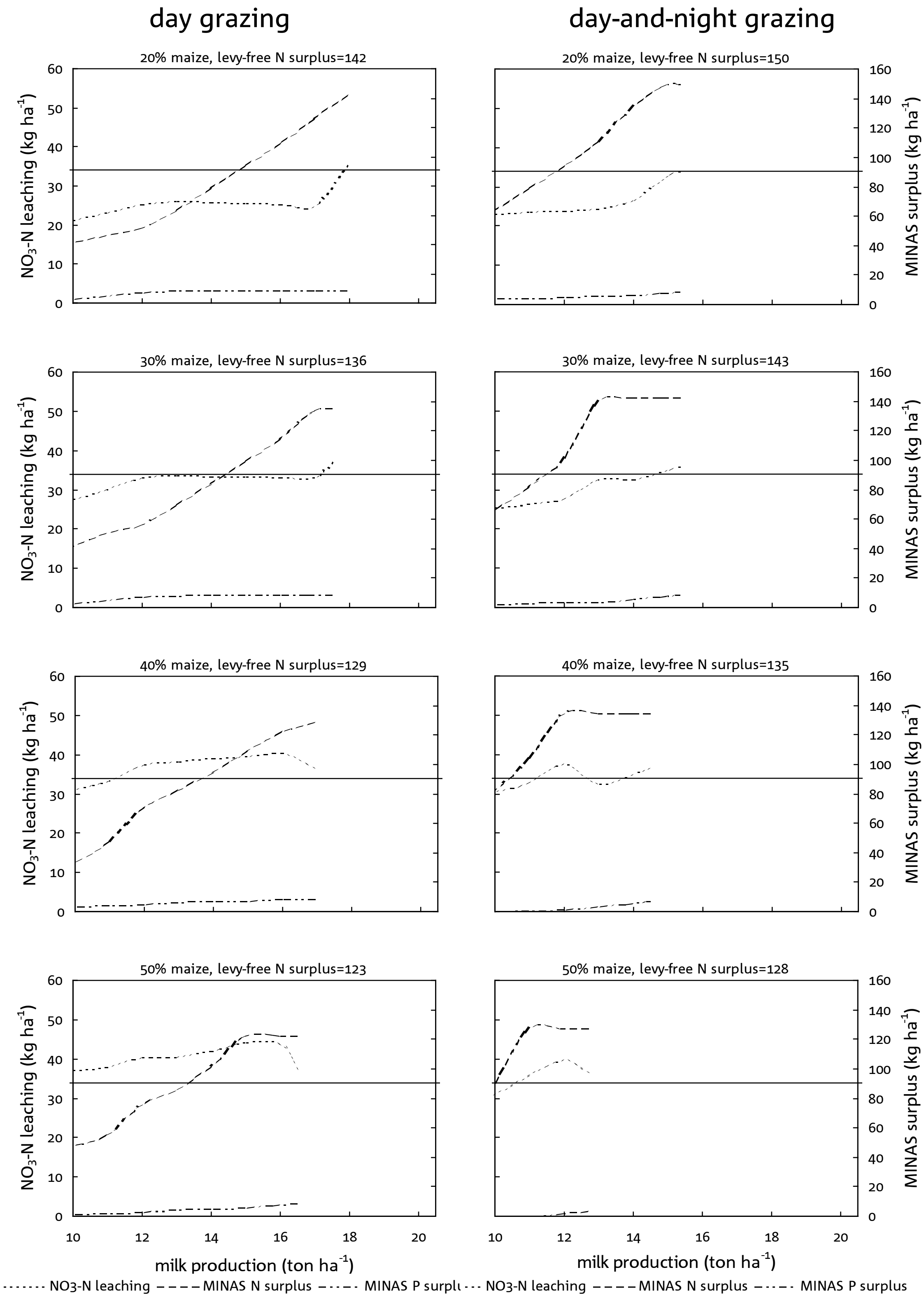

Figure 6.6. *(continued) Relationship between milk production level (x-axis), NO_3-N leaching (left y-axis) and MINAS surplus (right y-axis) with 20, 30, 40 and 50% maize and with levy-free N surpluses according to Table 6.1 under four grazing systems.*

Figure 6.6 leads to the following observations:

1) With milk production unrestricted, MINAS N and P surpluses equal levy-free surpluses for each combination of grazing system and maize/grassland ratio. When milk production per ha is restricted to a lower value, MINAS N surpluses instantly attain values below levy-free N surpluses. Hence, the newly-derived levy-free N surpluses only affect labour income and NO_3-N leaching in intensive dairy farming systems that realise high milk production levels per ha.
2) MINAS P surpluses equal the levy-free P surplus (9 kg ha^{-1} for all situations) over a much wider range of milk production levels per ha, especially if grass areas are relatively large and in zero grazing systems (see Section 5.4.1 for explanation).
3) Lower milk production per ha and MINAS N surpluses below levy-free N surpluses do not necessarily result in lower NO_3-N losses.
4) If maize areas are below 30%, NO_3-N loss is generally around (at high milk production per ha) or even appreciably below (at reduced milk production per ha) 34 kg ha^{-1}.
5) If maize areas exceed 30%, NO_3-N loss generally exceeds 34 kg ha^{-1}, more or less irrespective of milk production per ha.

MINAS phosphorus

One way to bridge the gap between calculated MINAS P surplus and levy-free P surplus is to include P in mineral fertiliser as an input in the MINAS balance. Following implementation in the model, NO_3-N leaching decreases to 30 kg ha^{-1} and labour income is 5% lower than under current design of MINAS and the manure contract system. Contrary to the reference situation, the dairy sector refrains from purchasing mineral P-fertiliser, as that limits P-inputs with which milk can be produced, notably concentrates. This requires a more balanced distribution of slurry over maize and grassland, to maintain the P-status of both maize land and grassland[2]. As a result, less slurry is applied to maize land in autumn, and more to grassland. This explains the observed reduction in NO_3-N leaching.

[2] Note that in the reference situation, slurry is applied in the cheapest possible way, biased towards maize. Imminent P-shortages in grassland resulting from this unbalanced distribution are avoided by application of P in mineral fertiliser.

Consequences of including P in mineral fertiliser as an input term in the MINAS balance are similar for all grazing systems for similar reasons: considerable reductions in NO_3-N leaching (to values below 34 kg N ha^{-1} in all situations), associated with about 5% reduction in labour income.
Contrary to the arable sector, the reference dairy sector shows 'luxury' P-input, i.e. P-input exceeding annual P-output. Hence, reducing the gap between MINAS P surplus and levy-free P surplus might be effective in reducing N-losses in the dairy sector. Reducing the levy-free P surplus to e.g. 0, results in NO_3-N leaching of 38 kg ha^{-1} and labour income of 85% of that in the reference dairy sector. Main change is a reduction in P-input in concentrates, such that the MINAS P surplus equals the levy-free P surplus. Consequently, stocking rate and milk production per ha are constrained. Reducing the levy-free P surplus thus appears an ineffective measure to attain the goal of NO_3-N leaching in the dairy sector: it should be reduced to a value below zero, but then unnecessarily limits labour income. The main reason for its ineffectiveness is that it does not result in a strongly modified distribution of slurry over grassland and maize.

Nitrate Directive regulations

Strict implementation of Nitrate Directive regulations in the dairy sector implies that manure in excess of 170 kg N per ha arable land plus 250 kg N per ha grassland is either not produced or transferred to 'consumers' of manure. When maximising labour income in the dairy sector, all land in the region is selected for dairy farming, and no 'consumers' of manure are present. Hence, under a strict compliance regime, maximum manure production in the dairy sector is 170 kg N per ha arable land plus 250 kg N per ha grassland. Manure production is calculated in a standardised way, i.e. derived from default values for annual N excretion per animal category (see Table 5.1) and the number of animals of that category at the farm. Hence, Nitrate Directive regulations under a strict compliance regime *de facto* define a maximum animal number for the dairy sector. This number is determined by the relative maize area and grassland area. When maximising labour income in the dairy sector under a strict compliance regime, only grassland is selected, because grassland allows higher manure production per ha than maize land. Taking into account manure production by young stock and with all land under grassland, maximum stocking rate under a strict compliance regime is 1.81 dairy cows per ha, a substantial reduction compared to stocking rate under a flexible interpretation of Nitrate Directive regulations, as in the reference dairy sector (2.60 dairy cows per ha). Consequently, the dairy sector is strongly extensified and milk production (14 476 kg ha^{-1}), NO_3-N loss (7 kg ha^{-1}) and labour income (€ 1 386 ha^{-1}; -25%) appreciably reduced. MINAS N and P surpluses are below the levy-free surpluses.

If the derogation request is not granted, maximum manure production in the dairy sector is 170 kg N per ha, irrespective of whether land is under grassland or under maize. Strict compliance with Nitrate Directive regulations under that scenario results in still lower maximum stocking rate and further extensification of the dairy sector. Maximum labour income in that situation is € 820 ha^{-1}. The advantage of grassland compared to maize is absent, and about 25% of the land is used for silage maize cultivation. As a consequence, NO_3-N leaching increases to 22 kg ha^{-1}. MINAS N and P surpluses are below the levy-free surpluses.

6.3.3 Specialised farming systems

In Chapter 5, regional labour income was maximised for specialised farming systems under current design of MINAS and the manure contract system, under the restriction that at least 50% of the area should be used by the arable sector, to prevent allocation of all land to the dairy sector. NO_3-N leaching associated with maximum regional labour income was 54 kg ha^{-1} in the arable sector and 42 kg ha^{-1} in the dairy sector. Leaching was mainly caused by cultivation of arable crops and silage maize at economically optimal yields, combined with high slurry doses.

In calculations at regional scale presented below, the restriction on the minimum area under arable crops is again used.

MINAS nitrogen

Results pertaining to the design of the MINAS N balance as reported in Sections 6.3.1 and 6.3.2 for the arable and dairy sector are introduced in calculations at the regional scale. Hence, regional labour income is maximised with levy-free N surplus in the arable sector set to -60 kg ha^{-1} and levy-free N surpluses per ha grassland and maize set to 145 and 80 kg ha^{-1}, respectively. Maximum regional labour income under these conditions (€ 1 578 ha^{-1}) is 96% of that in the reference specialised farming system. Labour income in the dairy sector is unaffected, while that in the arable sector is reduced by 15%. NO_3-N leaching in the dairy and arable sector is 45 and 40 kg ha^{-1}, respectively. NO_3-N leaching in both sectors thus appears higher than expected on the basis of calculations at sector scale. This has different reasons for the arable and dairy sector. In the arable sector, cattle slurry input is maintained at the maximum allowed (85 kg N ha^{-1}) and a MINAS N levy is accepted. Rationale is that labour income in the dairy sector can be maintained at its original value, which is attractive from the perspective of regional labour income, but not from the perspective of labour income in the arable sector. Design of the dairy sector is about equal to that in the reference specialised farming system. Reason that leaching in the dairy sector exceeds 34 kg N ha^{-1}, despite the modified levy-free N surpluses (Table 6.1) is that the latter were derived for dairy farming systems in which export of manure was not allowed. At regional scale, manure export from the dairy sector to the arable sector is allowed, hence the dairy sector can partly shift losses associated with manure application to the arable sector. This creates opportunities within the dairy sector to use N less efficiently and increase the maize area to 26%, with the aim to maximise labour income.

MINAS phosphorus

As illustrated in Section 6.3.1, NO_3-N loss in the arable sector can not be reduced via adjustments of the MINAS P balance. In the dairy sector, an effective adjustment is inclusion of P in mineral fertiliser as input term, as that results in a more balanced distribution of slurry over grassland and maize.

Inclusion of P in mineral fertiliser as input term in the MINAS P balance of the dairy sector is also effective at regional scale: when maximising regional labour income, NO_3-N leaching in the dairy sector is 32 kg ha^{-1} (compared to 42 kg ha^{-1} in the reference specialised farming system; Table 5.12). Underlying cause is the same as at sector scale: the dairy sector refrains from purchasing mineral P-fertiliser, and this requires a more balanced distribution of slurry over the farm to maintain the P-status of both maize land and grassland. Regional labour income (€ 1 543 ha^{-1}) is 94% of that in the reference specialised farming system.

Nitrate Directive regulations

Strict compliance with Nitrate Directive regulations at regional scale only affects the dairy sector: it limits standardised manure production in that sector to 170 kg N per ha maize land plus 250 kg N per ha grassland plus the slurry-N transferred to the arable sector. When maximising regional labour income under a strict compliance regime, only grassland is selected in the dairy sector and the maximum amount of cattle slurry is transferred to the arable sector. Compared to the reference specialised farming system, regional labour income (€ 1 402 ha^{-1}) is reduced by 15%, entirely attributable to a reduction in labour income in the dairy sector. Due to the absence of maize cultivation, NO_3-N leaching in the dairy sector is only 10 kg ha^{-1}. Strict compliance with Nitrate Directive regulations does not affect NO_3-N loss in the arable sector, which remains too high. MINAS surpluses in the arable and dairy sector do not exceed levy-free surpluses.

6.3.4 Mixed farming systems

In Chapter 5, regional labour income was maximised for mixed farming systems under current design of MINAS and the manure contract system, under the restriction that at least 50% of the area should be under arable crops. NO_3-N leaching associated with maximum regional labour income was 81 kg ha^{-1}. Leaching was mainly caused by high slurry applications to arable crops. MINAS N and P surpluses were 140 and 9 kg ha^{-1}, respectively, both equal to the levy-free surpluses. Hence, no gap exists between actual MINAS surpluses and levy-free surpluses, so that reducing levy-free surpluses will instantly affect labour income and, possibly, N-emissions.

Similar to the dairy sector, when reducing levy-free surpluses for the mixed farming system, it is more likely that the design of the farming system is adapted, rather than that MINAS levies are paid. Another similarity with the dairy sector is land use, consisting of a combination of grassland and arable crops (the latter comparable to maize in the dairy sector).

In calculations for mixed farming systems presented below, the restriction of 50% area minimally under arable crops is again used. With the grassland phase fixed at 4 years, this implies that the length of the arable phase of the rotations considered is either 4, 5 or 6 years. Associated levy-free N surpluses are 140, 136 and 132 kg ha^{-1}, respectively.

MINAS nitrogen

In a series of optimisations, it is explored to what extent MINAS N surplus in each of the three considered rotation lengths needs to be reduced to comply with the goal for NO_3-N leaching (Figure 6.7). In addition to NO_3-N loss, labour income index (percentage of maximum labour income in each rotation) as a function of MINAS N surplus is plotted. Maximum MINAS N surpluses to comply with the policy standard for NO_3-N leaching amount to 100, 85 and 65 kg ha^{-1} with arable phases of 4, 5 and 6 years (Figure 6.7). Main change induced is a shift from autumn application of animal manure to arable crops to application to grassland. Labour income and other characteristics of the farming system are hardly affected.

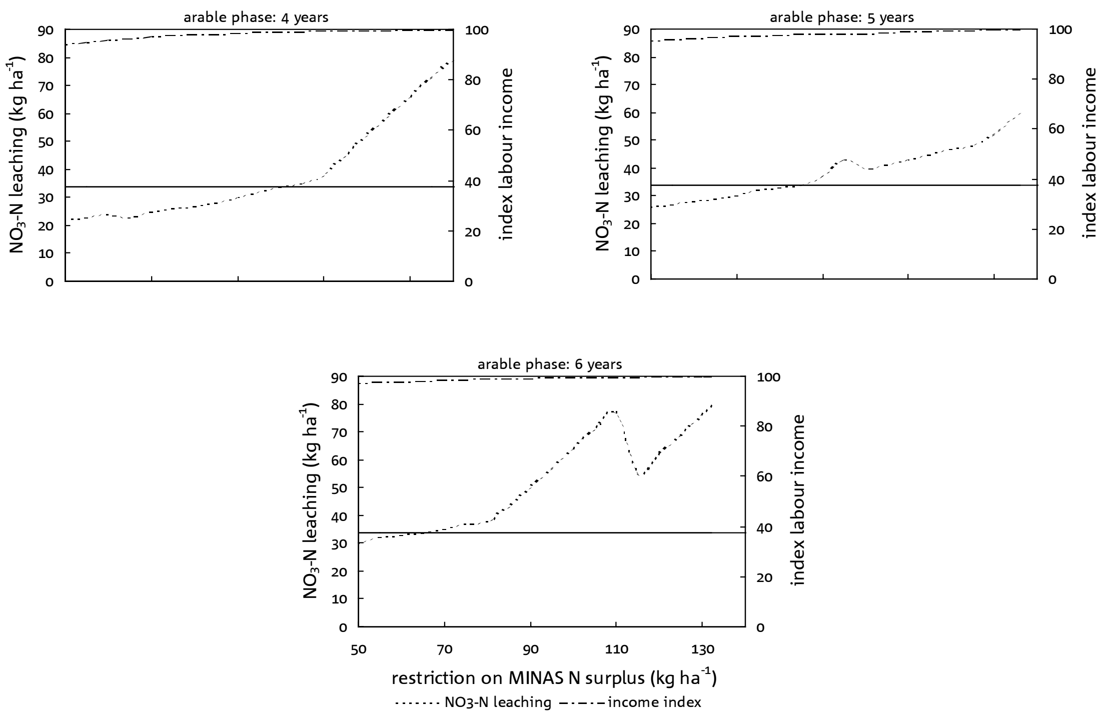

Figure 6.7. Relationship between MINAS N surplus (x-axis), NO_3-N leaching (left y-axis) and labour income index (right y-axis) in mixed farming systems with arable phases of 4, 5 and 6 years.

The gap between maximum N surplus to comply with the standard for NO_3-N leaching and current levy-free N surplus increases with the length of the arable phase. This gap equals 40, 50 and 65 kg ha^{-1}, when the length of the arable phase is 4, 5 and 6 years, respectively. Unfortunately, an increasing gap with increasing length of the arable phase implies that it is not possible to define a single pair of levy-free N surpluses per ha grassland and per ha arable crops, that is effective in restricting levy-free N surplus at farm scale to maximum MINAS surpluses (Figure 6.7) for each rotation length.
As noted, to some extent, mixed farming systems considered here are comparable with a specialised dairy farming system with a very large maize area (>50%). Note accordingly that also for the dairy sector it appeared impossible to define one single pair of levy-free N surpluses that is effective in sufficiently reducing NO_3-N loss at all ratios of grassland and maize.

MINAS phosphorus

Including P in mineral fertiliser as input in the MINAS balance of mixed farming systems is not effective in reducing NO_3-N loss. While, as in the dairy sector, P-input with mineral fertiliser is avoided, it does not result in a strongly modified distribution of slurry over arable land and grassland. This is the consequence of the formulation of the constraint in the MGLP model requiring P-outputs to be at least compensated by P-inputs to maintain the P-status of the soil. In specialised farming systems, this constraint applies to each of the physically separated units, arable crop rotation, permanent grassland and continuously cropped maize, whereas in mixed farming systems the constraint applies to the entire, physically integrated crop rotation.
P-input in the reference mixed farming system exceeds annual P-output ('luxury' P-input). Reducing the gap between MINAS P surplus and levy-free P surplus is however not effective in reducing NO_3-N loss, for similar reasons as in the dairy sector (Section 6.3.2).

Nitrate Directive regulations

Strict implementation of Nitrate Directive regulations in mixed farming systems results in 20% reduction in labour income of the reference mixed farming system to € 1 900. Under this constraint, leaching loss is 56 kg N ha^{-1}. This is caused by arable crops receiving fairly high doses of animal manure. MINAS N surplus is below the levy-free surplus. The MINAS P surplus equals the levy-free surplus.

If the derogation request is not granted, maximum labour income is reduced to € 1 615 and leaching to 50 kg N ha^{-1}, again associated with slurry application to crops.

6.4 Discussion

6.4.1 MINAS nitrogen

Arable sector

Model calculations for the arable sector show that the levy-free N surplus should be reduced to -60 kg ha^{-1} to restrict leaching loss to 34 kg N ha^{-1}.

Schröder *et al.* (2000) estimated levy-free N surpluses for arable land that result in (1) NO_3 concentration in upper groundwater below sandy soils not exceeding 50 mg per litre and (2) total-N concentration in surface waters not exceeding 2.2 mg per litre. Estimates were based on Monte Carlo simulations, taking into account uncertainties in the relationship between levy-free N surplus and N-concentration in groundwater and surface water, respectively. Given these uncertainties, levy-free N surplus for arable land should be between 50-125 kg ha^{-1} (average 88) to attain the first goal, and between -50 and 130 kg ha^{-1} (average 40) to attain the second goal. Both ranges of levy-free N surpluses are distinctly higher than quantified in this study. Higher permitted levy-free N surpluses are explained by higher permitted NO_3-N losses per ha arable crops in the study of Schröder *et al.* (2000). In their study, a NO_3-N loss exceeding 34 kg ha^{-1} in most cases did not violate environmental goals for groundwater and surface waters, depending on assumptions with respect to precipitation surplus and denitrification rates in top soil, sub-soil and ditches. Average levy-free N surpluses for arable land as proposed by Schröder *et al.* (2000) imply that the current levy-free N surplus for arable crops should be reduced by 12 and 60 kg N ha^{-1}.

In 1999/2000, that is before the introduction of MINAS, 10% of all arable farms realised MINAS N surpluses below -50 kg ha^{-1}, 50-60% below the current levy-free surplus, and 75% below 150 kg N ha^{-1} (de Hoop, 2002). These data suggest that MINAS affects nutrient management and nutrient losses in the arable sector only to a limited extent, i.e. only affecting the real 'bunglers'. Based on model calculations, Oenema *et al.* (2002) estimate that introduction of MINAS reduces NO_3-N emission from agriculture to surface waters by 23-33% at national scale (reference year: 1985). The goal is a 50% reduction. Data from de Hoop (2002) and Oenema *et al.* (2002) support the finding in this study, i.e. if MINAS is to substantially reduce NO_3-N loss from the arable sector, the current levy-free N surplus should be considerably reduced.

Dairy sector

Modelled NO_3-N loss in the dairy sector is strongly linked with the maize area and with N-fertilisation of that crop. When maximising labour income for the dairy sector, maize is selected because the crop has two advantages compared to grass: (1) maize in the ration results in lower N-excretion per dairy cow, and (2) the organic N balance of maize offers more space to apply and hence produce manure. Both advantages allow higher stocking rates (see Section 5.4.4 for detailed explanation).

When gradually restricting the levy-free N surplus in the dairy sector to the point where the policy standard for NO_3-N leaching is attained, it becomes increasingly important to reduce N-losses and increase N-use efficiency. Available and effective options in the dairy sector are to reduce the maize area and/or to reduce slurry-N application in maize. In the model, consistently, only one of these options is selected, i.e. reduction of the maize area, while N-fertilisation of maize consistently is entirely as slurry. This shows that partial substitution of slurry-N by fertiliser-N, which would allow a larger maize area, is unattractive from the perspective of labour income. Explanation is that, per unit of effective N applied, net energy yield per ha grassland is higher than net energy yield per ha maize. This leads to the conclusion that maize in the MGLP model is merely selected to 'dump' manure. Interestingly, manure dumping purposes were one of the reasons behind the boost in maize cultivation occurring in the first half of the 1980s (Schröder & Dilz, 1987). Up to this date, N-fertilisation of maize is characterised by high slurry applications (derived

from Reijneveld *et al.*, 2000). Probably related to this, NO_3-N leaching per ha under maize is higher than under grassland and arable crops (Oenema *et al.*, 2002, based on model calculations).
The necessity to adjust the MINAS N system to attain the standard for NO_3-N leaching in the dairy sector emerges from model calculations and almost exclusively arises from maize cultivation and its N-fertilisation. In practice, the desirability to adjust MINAS only to improve N-use efficiency in maize cultivation, can be questioned: it would affect all farmers, including those that work neatly.

6.4.2 MINAS phosphorus

Including P in mineral fertiliser as input term in the MINAS balance is an effective measure to reduce NO_3-N loss when it induces a shift of manure application from arable crops/maize to grassland. Model results show that this effect occurs in the dairy sector only. Underlying 'mechanism' in the model is the avoidance of P-input with mineral fertiliser, consequently requiring a balanced distribution of slurry-P application over the physically separated units, permanent grassland and continuously cropped maize. In the mixed farming system, P-input with mineral fertiliser is also avoided, but then does not result in a modified distribution of slurry, as land use units are not physically separated. The reference arable sector is unaffected when including P in mineral fertiliser in the MINAS balance: even with mineral P in the MINAS balance, MINAS P-surplus is well below the levy-free P surplus.
Currently, application of P in mineral fertiliser is not constrained by MINAS, and is used in considerable quantities (about 13 kg ha^{-1}). If mineral P fertiliser would be added to average MINAS P surpluses realised in 1999/2000 at commercial farms, many of these farms (covering all land-based agricultural sectors) would face a MINAS P-levy (derived from de Hoop, 2002). Hence, inclusion of P in mineral fertiliser in MINAS will certainly reduce total P-input at commercial farms. Whether that affects NO_3-N loss depends on decisions made by individual farmers on how to achieve the required reduction. As in the model, it does not seem unlikely that dairy and mixed farmers will first want to minimise mineral P fertiliser input, rather than e.g. P-input via concentrates, possibly resulting in a more balanced distribution of slurry. Arable farmers will have to weigh manure-P against P in mineral fertiliser. Rather speculatively, arable

farmers might have a preference for P in mineral fertiliser, e.g. because determination of available P-amounts in animal manures is wrought with uncertainty.

6.4.3 Nitrate Directive regulations

Nitrate Directive regulations under a strict compliance regime define a maximum to the standardised manure production, and hence to animal numbers. Strict implementation in specialised farming systems would result in abrogation of maize cultivation in the dairy sector. Hence, standardised manure production in the dairy sector under a strict compliance regime is limited to 250 kg N ha^{-1} (compared to 360 kg N ha^{-1} in the reference dairy sector). At regional scale, when 50% of the area is under grassland (constituting the dairy sector) and 50% under arable crops (constituting the arable sector), standardised manure production in the region is increased by the amount exported to the arable sector (85 kg N ha^{-1} arable crops) and totals 168 kg N per regional hectare (compared to 230 kg N ha^{-1} in the reference specialised farming system). With all land in the dairy sector under grassland, NO_3-N loss in that sector is low. NO_3-N loss in the arable sector is unaffected. In mixed farming systems, with 50% under grassland and 50% under arable crops, strict implementation limits standardised manure production to 210 kg N ha^{-1} (compared to 345 kg N ha^{-1} in the reference mixed farming system). The difference in maximum standardised manure production between specialised and mixed farming systems is caused by the assumption used in this study that the specialised arable sector concludes manure contracts for only half the permitted amount. In the mixed farming system, NO_3-N loss exceeds the standard of 34 kg N ha^{-1}, even when the derogation request would not be granted. Strict compliance to Nitrate Directive regulations severely limits animal production and causes considerable reductions (15-25%) in labour income in the dairy sector and in the mixed farming system.

6.4.4 The role of MINAS in reducing NO_3-N loss

The model results indicate that it is not possible to identify one single pair of levy-free N surpluses for grassland and arable crops that is effective in restricting NO_3-N loss to 34 kg ha^{-1} in all considered farming systems. The main reason is the difference in NO_3-N leaching loss between grassland and arable crops. This loss under arable crops is supposedly higher than under grassland (Oenema *et al.*, 2002; Conijn, 2000). Hence, when all land is allocated to arable crops, the required MINAS N surplus to attain the standard for NO_3-N leaching is lowest (-60 kg N ha^{-1}). When land is partly allocated to grassland (in the dairy sector and in mixed farming systems), MINAS N surpluses can be much higher without exceeding maximum permitted NO_3-N leaching. Results for the dairy sector and the mixed farming system suggest that different sets of levy-free N surpluses should be defined, depending on grazing system and the ratio of grassland and maize/arable land.

The balance between manure production and manure application opportunities in the Netherlands, combined with Dutch manure policies, has, since the second half of the 1990s, led to the situation that arable farmers are paid for manure application to their crops. Hence, besides being a source of nutrients and organic matter, manure application at arable farms has become a source of income. As a result, manure use at arable farms has increased in some regions of the Netherlands, associated with an increase in N surpluses (de Hoop, 2002). Probably, these increases in manure use and N surpluses are associated with increased NO_3-N losses, especially because increased manure use occurred in clayey areas, where manure is applied in autumn. The MINAS system and the manure contract system in the arable sector will top off excessive manure use at arable farms, but still leave room for inefficient use of manure-N (this study; van Dijk & van der Schoot, 1999). The extent to which arable farmers use manure in the future partly depends on the national balance between manure production and manure application opportunities, because this balance determines the price arable farmers receive or pay for manure use.

The impossibility of defining a single pair of effective levy-free N surpluses for grassland and arable land and the room MINAS leaves for polluting activities, point to a disadvantage of a target-oriented and relatively simple system, such as MINAS, with which one single goal, reduction of NO_3-N loss, should be attained across a wide variety of agricultural holdings. Effective additional instruments in Dutch manure policy could therefore be means-oriented regulations, specifically aimed at reducing NO_3-N leaching. Examples of such instruments are the obligation to apply manure in spring or to combine autumn application of manure with catch crop cultivation, adjusting manure application rate to N uptake capacity of the catch crop. Such regulations could also bring closer the implementation of good agricultural practice. The Nitrate Directive prescribes that EU Member States establish such codes, to be implemented by farmers on a voluntary basis. According to Dekking (2000), spring application of manure on clay soils is technically feasible, and results in financial gains compared to using mineral fertilisers only. Adoption of spring application in commercial farming is however still limited, due to farmers' perceptions about consequences for soil structure and product quality, and due to organisational constraints (Dekking, Institute of Applied Research for Arable Farming and Field Production of Vegetables, pers. comm.). The latter refer to the tuning of weather and soil conditions, on-farm tasks and the availability of the contract-labourer, hired for manure application.

6.5 Conclusions

- A gap exists between levy-free N surpluses foreseen for 2003 and levy-free N surpluses required to attain the standard for NO_3-N leaching. This gap is larger as arable cropping and/or maize cultivation are more important in terms of area use and increases in the order dairy farming (15-30 kg N ha^{-1}), mixed farming (40-65 kg N ha^{-1}) and arable cropping (160 kg N ha^{-1}). Bridging this gap has limited effects on labour income in all situations.

- If MINAS is to substantially reduce NO_3-N loss from agriculture, levy-free N surpluses should be differentiated according to farming system (arable cropping, dairy farming, mixed farming), grazing system and the ratio of grassland and arable land. Such a differentiation is likely to severely complicate the feasibility and enforceability of the MINAS system.

- Inclusion of P in mineral fertiliser as input term in the MINAS balance is an effective measure to reduce NO_3-N loss in the dairy sector, as it results in more balanced distribution of slurry over maize and grassland.

- Means-oriented regulations, specifically aimed at reducing NO_3-N leaching, are useful additional instruments in Dutch manure policy.

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CHAPTER 7

Impact of Agenda 2000 and full trade liberalisation on optimal configuration of specialised and mixed farming systems

7.1 Introduction

At the European Summit in Berlin, March 1999, the European Union Heads of States reached agreement on the Agenda 2000 package, which contains reforms of the Common Agricultural Policy (CAP). The Agenda 2000 reforms have been mainly prompted by trade policy considerations related to expansion of the European Union (EU) and compliance with World Trade Organisation (WTO) regulations. To what extent the CAP complies with WTO regulations after implementation of Agenda 2000 reforms is unsure (see below). The CAP will be up for further review in 2002/2003 (the so-called mid-term review). This review might result in new reform decisions. Besides trade policy considerations, future CAP reforms could also be derived from other considerations, as the CAP is increasingly criticised for its adverse effects on third world countries, nature, environment, consumers and tax-payers.

In this chapter the impacts of two future scenarios on optimal configuration of specialised and mixed farming systems and on labour income per ha are quantified. The first scenario represents Agenda 2000. The second scenario is derived in response to the existing criticism on the CAP and implies elimination of all product-tied support (Full Liberalisation). Configurations of specialised and mixed farming systems under the Agenda 2000 and Full Liberalisation scenarios are compared with those given in Chapter 5, i.e. under the Reference scenario.

7.2 Criticism on the CAP

7.2.1 Impact on developing countries

Oxfam International, a confederation of twelve non-governmental development agencies, argues that no sector of world trade is more distorted than agriculture (Anonymous, 2002a). Global markets are dominated by industrial countries, largely by virtue of heavy subsidies, while farming in those countries contributes a negligible proportion to Gross Domestic Product, employment and export earnings. Due to existing industrial-country agricultural policies, producers in developing countries face severe export restrictions and low world market prices, resulting in lost market shares and unfair competition in local markets. The resulting financial loss for developing countries by far outweighs the benefits of development aid (Anonymous, 2002a).

According to Oxfam International, during the Uruguay Round Agreement on Agriculture (URAA) in 1994, European and US negotiators turned the debate on agricultural trade liberalisation into a game of semantics. Having agreed in principle to reduce subsidies, rich countries proceeded to change the definition of 'subsidy' to allow them to continue on a business-as-usual basis. Oxfam International acknowledges that government intervention in agriculture in both developing and industrialised countries can be important to promote legitimate rural development and environmental objectives. However, in their view, the problem is that the current systems of support in the EU - and USA - fail to deliver the social and environmental outcomes that they claim to promote - acknowledged for the EU by e.g. van der Bijl (1999) and Lowe & Brouwer (2000); see below -, while having a devastating effect on poor farmers in developing countries. In short, Oxfam International blames rich countries of preaching free trade rhetoric, while adhering to protectionist practice. In the view of Oxfam International, a fairer CAP ends all subsidised exports, transfers production-linked subsidies to subsidies for rural development and ends EU-pressure on developing countries to liberalise their agricultural markets.

7.2.2 Impact on agricultural biodiversity and environment

It is generally agreed that high product prices paid under the CAP have encouraged greater use of external inputs than would otherwise have been the case (Brouwer & Lowe, 1998; Brouwer & van Berkum, 1996). This has led to a less efficient use and hence a larger potentially polluting surplus of inputs (mineral fertilisers, manures, pesticides). Therefore, the CAP is criticised for promoting intensive and environmentally damaging methods of production (e.g. Harvey, 1997; Pain & Pienkowski, 1997; Lowe & Brouwer, 2000). Van der Bijl (1999) concludes that integration of environmental criteria in the CAP as regards internalisation of negative environmental effects, the incorporation of environmental efficiency indicators and targets, and assessments of the environmental impact of proposed policy reforms, is limited. In addition, Member States fail to introduce cross-compliance measures with considerable

Table 7.1. Some indicators of agricultural intensity in European countries. All data in kg ha^{-1} utilised agricultural area. Data for nitrogen refer to 1997. Data for pesticides refer to the early 1990s. (Sources: Anonymous, 2002b; Brouwer & van Berkum, 1996).

Country	mineral N fertiliser use	manure-N production	total-N	N surplus	Pesticides (active ingredient)
Netherlands	186	307	493	249	17.5
Belgium	124	187	311	178	10.7
Denmark	105	100	205	112	2.2
Ireland	91	110	201	75	2.2
Germany	104	75	179	56	4.4
United Kingdom	84	61	145	87	3.6

environmental benefits, whilst take-up of other instruments, such as modulation[1], has been low (CEC, 2002).

Relative to other European countries, intensification of agriculture has proceeded to a particularly high level in the Netherlands, as illustrated in Table 7.1. Intensive crop and livestock production has had harmful effects on the quality of soils, air and water, bio-diversity and landscape. Wild plant populations in agricultural landscapes have been decimated. Some bird species typical for agricultural landscapes have recently become extinct (e.g. Ortolan bunting), some are near extinction (e.g. Corn bunting), while populations of other, once-common species have strongly declined in numbers and ranges (e.g. Grey partridge, Skylark, Black-tailed godwit). It is difficult to ascribe reasons behind declining numbers and distribution or extinction to specific causes, but the body of evidence that it relates to what is generally termed 'intensification of agriculture' is massive (e.g. Chamberlain *et al.*, 2000; Pain & Pienkowski, 1997). Tucker (1997) argues that conservation objectives should be integrated into all aspects of EU agricultural policies, aimed at maintenance of existing low-intensity farming systems, the avoidance of further intensification, the restoration of agricultural habitats of high nature conservation value, the

[1] Modulation enables Member States on a voluntary basis to reduce direct payments granted to individual farms and to spend the money saved in rural development programmes.

reduction of inputs in highly intensified systems and appropriate restoration of important habitat features, such as hedgerows and ditches.

7.3 The scenarios

7.3.1 Agenda 2000

The Agenda 2000 package contains reforms of the CAP to prepare European agriculture for future internal and external changes. Internal change is the planned admission of 10 Central and Eastern European Countries (CEECs) to the EU. Maintaining the current high domestic EU prices of agricultural commodities would result in an unacceptable burden on the EU budget, given the high share of agriculture in CEECs total production. In addition, high EU food prices would have severe consequences for household expenditures in CEECs. External changes relate to EU commitments derived from the URAA, where rules were established to facilitate access of third countries to European markets and to limit volumes and expenditures on subsidised EU exports and levels of domestic price support. Agenda 2000 decisions basically continue along the lines of the 1992 Mac Sharry reforms and imply a continued shift from domestic market price support towards direct payments to farmers. The reform aims at a more competitive and environmentally friendly European agriculture. Agenda 2000 measures are gradually implemented over the period 2000-2008. Key features of the reform, relevant to this study and after full implementation, include the following (CEC, 1999a).

The intervention price for cereals is reduced in two stages, totalling 15% in 2008. Reduced price support for cereals is partially compensated by increased direct area payments (CEC, 1999b; Anonymous, 2000a). Producers opting for area payments in excess of 12.99 ha, have to put 10% of that area under set-aside. This fraction may be modified later in the light of market developments.

As for cereals, intervention prices for butter and skimmed-milk powder will be reduced by 15% by the year 2008 (CEC, 1999c). The reduction is implemented in three stages, starting in 2005/2006. To compensate income loss, two types of direct payments are introduced: an EU-wide fixed payment - the so-called dairy premium; € 17.24 per ton of milk quota in 2008 - and additional payments. Additional payments are granted by individual member states on the basis of national, as yet unknown, criteria. Additional payments are therefore denoted

'national envelopes' and comprise so-called 'top-up' premiums and area payments. Total additional payments amount to € 7.63 per ton of milk quota. Due to the reduction in intervention prices, opportunities to export EU dairy products are expected to increase. Consequently, total EU milk quotas can be increased. Total increase until 2008 is 2.4%. The milk quota system will be evaluated in 2003, with a view on its discontinuation after 2006.
Part of the Agenda 2000 reforms deals with integrated rural development, constituting the second pillar of the CAP. Objective of this second pillar is to improve the economic and social integration of all rural areas. This aspect falls outside the scope of this study.

7.3.2 Full Liberalisation

The Agenda 2000 package certainly represents a move in the direction of liberalisation, with EU and world market prices of main export products getting closer. However, Agenda 2000 is mainly directed towards alleviating future problems associated with EU enlargement and compliance with existing URAA commitments. To what extent export subsidies will be eliminated, critically depends on world market developments, hence is unsure. In addition, compensatory payments to farmers are not completely production-neutral. Therefore, Agenda 2000 is not considered WTO-compatible (Swinbank, 1999; Agra-Europe, 1999), while other grounds for criticism on the CAP still remain (e.g. Myers, 1998). It is, therefore, likely that further changes to the CAP in the direction of liberalisation are needed within the next few years (Swinbank, 1999; Lowe & Brouwer, 2000) with the following potential implications:

1. it is generally assumed that lower agricultural supports will lead to reduced environmental impact, either by encouraging more efficient use of inputs or a shift to more extensive systems (Brouwer & Lowe, 1998);
2. improved market access for non-EU farmers, including those in developing countries;
3. prices of agricultural products, paid by consumers, will be lower, as will be the burden on the EU budget, financed by the tax payer (Folmer *et al.*, 1995);
4. while meeting WTO-requirements, the EU budget currently used for product-related support, can be used to remunerate farmers for their contribution to realisation of societal objectives other than food production.

In this chapter, further liberalisation of agricultural markets is radically interpreted as Full Liberalisation: producing against world market prices and abandonment of all direct payments coupled to agricultural production, including direct area payments.

7.4 Methodology

Implementation of Agenda 2000

Intervention price reductions as laid down in the Agenda 2000 package (see above) are assumed to result in equally reduced producer prices. Hence, producer prices of products of winter wheat cultivation and milk are reduced by 15% and area payments for winter wheat, maize and green pea adapted (Table 7.2). Direct payments per ton of milk quota are introduced, neglecting the national criteria used to grant additional payments. Hence, the EU-wide fixed payment and the additional payments are added, yielding a total direct payment of € 25 per ton of milk quota (Table 7.2). The cereal intervention price reduction provides an incentive to increase the share of cereals in compound feeds and is expected to result in a reduction in compound feed prices. Price reduction of compound feeds for growing pigs in the Netherlands is estimated at 13% (Brouwer *et al.*, 1999). An equal price reduction is assumed for concentrates. All other input and output prices remain as in the Reference scenario.

The reduced producer price for winter wheat affects the fertiliser/wheat price ratio, and hence the economically optimal N rate as calculated in Chapter 3 for the Reference scenario. Therefore, for winter wheat production techniques, adapted input-output coefficients have been generated.

Implementation of Full Liberalisation

Full Liberalisation is implemented in the MGLP model by eliminating all direct payments and setting producer prices to world market prices. World market prices could not be derived from official publications (e.g. Anonymous, 2000b), because these differ from world market prices relevant to the EU, as the EU

exports its agricultural products to specific markets with deviating prices. Alternatively, EU-relevant world market prices for arable products were derived from Anonymous (1998), where the ratio of internal EU price and EU-relevant world market price is determined. Without Agenda 2000 reforms, the ratio for winter wheat and sugar beet expected for the year 2005, is 1.22 and 1.41, respectively (Anonymous, 1998). Hence, to arrive at prices under the Full Liberalisation scenario, producer prices for winter wheat and sugar beet in the Reference scenario are reduced by 18 and 30%, respectively (Table 7.2). The world market price of milk is set to € 182 per ton (Anonymous, 1996; Boots, 1999; Besseling *et al.*, 2001), corresponding with a 45% reduction in the price in the Reference scenario. Purchase prices of compound feeds and concentrates are assumed equal to those under the Agenda 2000 scenario. Prices of all other inputs and outputs are kept equal to those in the Reference scenario. As under the Agenda 2000 scenario, reduced producer prices for winter wheat and sugar beet affect economically optimal N rates as calculated in Chapter 3 for the Reference scenario. Therefore, for winter wheat and sugar beet production techniques modified input-output coefficients have been generated.
In the Full Liberalisation scenario farm-income is assumed to be supplied by additional conditional and production-neutral payments, to remunerate farmers for their contributions to societal goals, other than food production. These additional sources of income are not considered. Hence, the effects of Full Liberalisation on labour income are quantified, only as derived from the production of agricultural goods.

Optimisations

In all optimisations, labour income is maximised. First, sectoral labour income under the Agenda 2000 and Full Liberalisation scenarios is maximised for each of the three agricultural sectors, arable cropping, pig production and dairy farming. In subsequent optimisations regional labour income is maximised for specialised farming systems and mixed farming systems.

7.5 Results

7.5.1 Arable sector

The only 'major' change induced by Agenda 2000 in the arable sector is a 15% reduction in the producer price of winter wheat, partially compensated by an increase in the area payment for the crop. Associated reductions in economically optimum grain yield and N-rate, and hence modifications of input-output coefficients of winter wheat production techniques, are insignificant. Maximum labour income per ha in the arable sector is also hardly affected: it is reduced by only 3% to € 900 ha^{-1} (Table 7.3). All agronomic properties of the selected farming system are about equal to those in the Reference scenario (see Table 5.2). Hence, the reduction in labour income in the arable sector is largely explained by the net effect of reduced revenues from the sale of winter wheat grains (€ 40 ha^{-1}) and increased revenues from the area payment (€ 16 ha^{-1}). Labour income in the pig sector associated with maximum labour income in the arable sector increases from € 80 ha^{-1} (Reference scenario) to € 292 ha^{-1} (Table 7.3). The increase is entirely attributable to lower purchase prices of compound feeds. The increase in labour income in the pig sector more than compensates the reduction in the arable sector, so that regional labour income per ha increases by 18%.

Major consequences of implementation of the Full Liberalisation scenario for the arable sector are reduced producer prices of winter wheat (-18%) and sugar beet (-30%) and the removal of all direct area payments. Despite these rather comprehensive changes, crop rotation is not different from that in the Reference scenario. Labour income in the arable sector is, however, reduced by 40% to € 557 ha^{-1}, as a result of removal of the direct area payment for winter wheat (€ 96 ha^{-1}) and reduced revenues from the sale of winter wheat (€ 25 ha^{-1}) and particularly sugar beet (€ 234 ha^{-1}) (Table 7.3). Maintaining sugar beet in the rotation, even after a 30% price reduction, highlights the large contribution of the crop to labour income in the arable sector under the Reference scenario and the limited importance of crops that are not selected (peas and white cabbage). Under the Full Liberalisation scenario, however, the competitive position of the latter crops improves, as differences in maximum labour income between alternative crop rotations become much smaller than under the

Table 7.2. Producer price indices and direct income support in the Reference, Agenda 2000 and Full Liberalisation scenarios.

	Producer price indices			Direct income support[1]		
	Reference	Agenda 2000	Full Liberalisation	Reference	Agenda 2000	Full Liberalisation
Winter wheat	100	85	82	386	446	-
Sugar beet	100	100	71	-	-	-
Silage maize	not affected			362	420	-
Pea	not affected			557	513	-
Milk	100	85	55	-	25	-

[1] *€ per ha arable crops and per ton milk.*

Reference scenario. For example, incorporating white cabbage in the crop rotation at the expense of sugar beet reduces maximum labour income by only € 42 ha^{-1}. In the Reference scenario, this difference is much larger (€ 275 ha^{-1}). Labour income in the pig sector at maximum labour income in the arable sector is about equal to that under the Agenda 2000 scenario. The increase in labour income in the pig sector does not fully compensate the reduction in the arable sector. The overall result is a 15% reduction in regional labour income, relative to the Reference scenario (Table 7.3).

7.5.2 Pig sector

Implications of Agenda 2000 of relevance to the pig sector include a 13% reduction in the price of compound feeds and a 15% reduction in the price of crushed wheat. This results in a 60% increase in maximum labour income in the pig sector, from € 421 ha^{-1} in the Reference scenario to € 666 ha^{-1} under Agenda 2000 (Table 7.3), which in addition to lower feeding costs, results from a small increase in the number of pig places per ha (from 6.6 to 7.3). The latter has become feasible because less crushed wheat is fed. This results in lower N-excretion per pig place, under the manure contract system allowing more pig places per ha than in the Reference scenario. Reduction in labour income in the

Table 7.3. Maximum labour income in the arable, pig and dairy sector in the Reference, Agenda 2000 and Full Liberalisation scenarios. All data in € per ha in the region. Optimised goals are in bold.

	Reference	Agenda 2000	Full Liberalisation
labour income arable sector	**926**	**900**	**557**
associated labour income pig sector	80	292	298
regional labour income	1006	1192	855
labour income pig sector	**421**	**666**	**667**
associated labour income arable sector	840	819	466
regional labour income	1261	1484	1134
labour income dairy sector	**1858**	**1636**	**-511**
associated labour income arable sector	0	0	0
associated labour income pig sector	0	0	21
regional labour income	1858	1636	-490

arable sector associated with maximum labour income in the pig sector is insignificant. Regional labour income increases by 18% relative to the Reference scenario to € 1 484 ha^{-1}.

Implementation of Full Liberalisation does not change the economic environment of the pig sector, compared to the Agenda 2000 scenario. Hence, maximum labour income in the pig sector under the Full Liberalisation scenario equals that under the Agenda 2000 scenario. Associated labour income in the arable sector is reduced by 45% compared to the Reference scenario.

7.5.3 Dairy sector

Implementation of Agenda 2000 in the dairy sector results in increased area payment for maize, 15% reduction in milk price, introduction of a milk premium per kg of milk quota (Table 7.2) and 13% reduction in purchase prices of concentrates. These changes combined result in 12% reduction in maximum labour income in the dairy sector to € 1 636 ha^{-1} (Table 7.3). Similar to the arable sector, agronomic properties of the selected dairy farming system are very similar to those under the Reference scenario. Hence, the change in labour income is not the result of a drastically changed dairy farming system design, but solely the net effect of reduced costs for concentrates (€ 265 ha^{-1}), reduced revenues from sale of milk (€ 1 020 ha^{-1}) and increased revenues resulting from the milk premium (€ 520 ha^{-1}) and maize premium (€ 11 ha^{-1}).

Full Liberalisation in the dairy sector almost halves the milk price and removes the area payment for maize. To facilitate interpretation of model results under the Full Liberalisation scenario, this scenario is fully introduced, except for the milk price, which is stepwise reduced in eight optimisations from the price in the Reference scenario (€ 328 ton^{-1}) to the world market price (€ 182 ton^{-1}), in each optimisation maximising labour income in the dairy sector. Only in the last of these optimisations, the Full Liberalisation scenario is fully implemented. This allows analysis of changes in revenues and costs in the dairy sector resulting from lower milk prices (Figure 7.1). Reducing the milk price to € 270 ton^{-1} does not induce substantial changes in configuration of the dairy sector. Milk production and total costs of production are maintained at their initial high levels, with dairy farming systems resembling those in the Reference scenario, characterised by high stocking rates, zero-grazing and maize cultivation on about 20% of the area. Revenues and labour income, however, decrease due to the lower milk price. When the milk price is reduced to a value below € 270 ton^{-1}, regional milk production and total costs of production fall

Figure 7.1. *Revenues, total costs and labour income (left y-axis) and milk production (right y-axis) in the dairy sector as affected by milk price in the Full Liberalisation scenario.*

considerably. Associated changes in dairy farming system design include cessation of maize cultivation, substitution of zero-grazing by day-and-night grazing and a reduction in stocking rate. Production costs (excluding labour costs) exceed revenues from milk production when the milk price is below € 215 ton^{-1}, and labour income consequently becomes negative. When the milk price is reduced from about € 200 ton^{-1} to the world market price, a further strong decline in milk production and total costs occurs, associated with a further reduction in stocking rate. At world market price, maximum labour income in the dairy sector is - € 511 ha^{-1}. Over the entire range of milk prices, production costs run parallel to milk production. Consequently, the cost price per ton milk is stable over the entire range of milk prices, equalling about € 250.

7.5.4 Specialised farming systems

The results at the scale of individual agricultural sectors showed that Agenda 2000 has a small negative effect on labour income in the arable sector, a moderately negative effect in the dairy sector and a large positive effect in the pig sector. Hence, implementation of Agenda 2000 improves the competitive position of the pig sector and weakens that of the arable and dairy sectors. This is reflected in the selection of pig production when maximising regional labour income in the Agenda 2000 scenario, as opposed to the Reference scenario (Table 7.4). Selection of pig production is at the expense of dairy farming, because the pig and dairy sector compete for limited manure application opportunities in the region. The combined effects of Agenda 2000 result in 5% reduction in maximum regional labour income, relative to the Reference scenario.

The results at the scale of individual agricultural sectors showed that the Full Liberalisation scenario has a large negative effect on labour income in the arable and dairy sectors and a positive effect in the pig sector. Hence, implementation of Full Liberalisation at regional scale improves the competitive position of the pig sector and dramatically weakens that of the arable and particularly the dairy sector. Mutual changes in competitive positions are such that, when maximising regional labour income in the Full Liberalisation scenario, all land is allocated to arable cropping, which is combined with free range pig production (Table 7.4).

Table 7.4. Maximum regional labour income in regionally specialised farming in the Reference, Agenda 2000 and Full Liberalisation scenarios. Optimised goal is in bold.

	Reference	Agenda 2000	Full Liberalisation
ratio dairy farming : arable cropping	50:50	50:50	0:100
regional labour income	**1646**	**1569**	**1160**
income arable sector	501	439	534
income pig sector	0	312	627
income dairy sector	1145	818	0
pig places	0	3.4	6.6
milk production	13195	10383	0

7.5.5 Mixed farming systems

As opposed to the specialised farming system, the configuration of the mixed farming system drastically changes after implementation of Agenda 2000. The selected strategy by the MGLP model fully exploits the reduction in costs of compound feeds, with the entire farming system serving free range pig production associated with an increase in labour income by about 5% (Table 7.5). The number of free range pig places is strongly increased to 20 ha^{-1} and their manure is applied in large quantities to arable crops and leys. The consequence of the large number of pig places is a large MINAS P surplus, exceeding the levy-free surplus by 25 kg ha^{-1}. Hence, payment of a high P-levy is accepted. Obviously, this farming system is associated with large N-losses. This result under the Agenda 2000 scenario much differs from that in the specialised farming system. Note that manure policy regulations in mixed farming systems allow a much higher manure production than in specialised farming systems. Apparently, this difference causes free range pig production in mixed farming systems to be more economically attractive than milk production.

Implementation of Full Liberalisation further reduces revenues from arable cropping and dairy farming activities, but does not alter the configuration of the mixed farming system relative to that under the Agenda 2000 scenario (Table 7.5).

Table 7.5. Maximum regional labour income in regionally mixed farming in the Reference, Agenda 2000 and Full Liberalisation scenarios. Optimised goal is in bold.

	Reference	Agenda 2000	Full Liberalisation
ratio dairy farming : arable cropping	50:50	40:60	40:60
regional labour income	**2375**	**2505**	**2108**
income from crop production	345	340	210
income from pig production	0	2171	2186
income from milk production	2030	-6	-288
pig places	0	20.1	20.1
milk production	19929	2485	2470

7.6 Discussion

7.6.1 Interpretation of model results

In this chapter, the impacts of Agenda 2000 and Full Liberalisation on configuration of specialised and mixed farming systems have been quantified, adopting a modelling approach. Agenda 2000 is an anticipated scenario, which will gradually be implemented over the years 2000-2008. The Full Liberalisation scenario is rather hypothetical, of which the effects on labour income, solely derived from the production of agricultural goods, are quantified. In this scenario, farm income is assumed to be supplemented by additional and conditional direct payments, to remunerate farmers for their contributions to societal goals other than food production. These additional sources of income have not been considered in this chapter.

The model results show that the impact of Agenda 2000 and Full Liberalisation on labour income varies among agricultural sectors. This implies that the scenarios affect the mutual competitiveness among sectors. Model results suggest that the competitive position of the pig sector improves, while those of the dairy and arable sectors weaken. These results do not necessarily imply that we will see an increase in the size of the pig sector and a decrease in the size of the arable and dairy sectors in the future, because that is determined by more factors than considered here. Such factors include:

(1) magnitude of direct payments, and the criteria used for granting;
(2) limits to expansion of agricultural sectors, as imposed by agricultural and other policies;
(3) impact of Agenda 2000 and Full Liberalisation on competitiveness of Dutch agricultural sectors from an international perspective;
(4) strategies adopted by farmers when confronted with producer price reductions.

Nevertheless, the scenarios do represent likely general trends in changes of farmers' economic environment, and the model results have at least indicative value. The possible impacts of the scenarios on Dutch agriculture are discussed below on a semi-quantitative basis, taking into account additional factors that were not accounted for in the model.

Arable sector

Implementation of Agenda 2000 in the arable sector only affected the revenues from winter wheat cultivation, leaving prices of all other crops intact. Hence, Agenda 2000 did not affect the configuration of the arable sector and hardly affected maximum labour income. Autonomous developments - i.e. developments under the pre-Agenda 2000 CAP - in the arable sector include the discontinuation of farms and take-over of their land by dairy farms and/or other arable farms (Besseling *et al.*, 2001).

Full Liberalisation has a large negative effect on labour income. Besseling *et al.* (2001) argue that the foundation of current Dutch arable farms, based on the cultivation of sugar beet, cereals and potato, disappears in a situation of full liberalisation. In coping with strongly reduced producer prices, arable farmers may choose to partly or fully leave farming, further enlarge the scale of production or convert to organic production. Remaining arable farms will in any case have gone through a metamorphosis. Besseling *et al.* (2001) foresee perspectives for sugar beet cultivation in the Netherlands, even in a situation of full liberalisation. These perspectives derive from a favourable physical environment and efficient processing. In accordance with this study, Besseling *et al.* (*op. cit.*) anticipate that sugar beet cultivation still realises higher financial margins than cultivation of cereals and/or fodder crops.

Pig sector

Model results show that Agenda 2000 and Full Liberalisation have a positive impact on labour income in the pig sector, derived from reduced feeding costs, resulting from the lower wheat price.

The pig sector has traditionally not been under heavy EU market regulations, and hence more or less produces under liberalised market conditions. Pig production in Europe is concentrated in regions where economic and infrastructural conditions provide a favourable competitive environment. One important factor determining the competitive position of the pig sector in a region is the cost price per pig delivered.

Before implementation of the Mac Sharry and Agenda 2000 reforms, EU cereal prices were much higher than currently. In response to the high cereal prices, the Dutch feed industry included cheaper cereal substitutes in animal feeds that could cost-efficiently be supplied through Rotterdam harbour. This resulted in lower feeding costs in the Dutch pig sector, relative to other regions, which contributed to a favourable competitive position of the Dutch pig sector (van Berkum *et al.*, 2002). The Mac Sharry and Agenda 2000 reforms have resulted in considerably reduced cereal prices and have stimulated inclusion of cereals in animal feeds at the expense of cereal substitutes since the second half of the 1990s. Consequently, the feed cost advantage resulting from the cost-efficient inclusion of cheaper cereal substitutes in the Netherlands has become much smaller (van Berkum *et al.*, 2002).

The competitive position of the Dutch pig sector is additionally affected by environmental and animal welfare legislation. Current and future legislation differs among countries, hence also affects the cost price per delivered pig differently. The impact of environmental and animal welfare legislation in the Netherlands is expected to further increase the cost price per pig delivered and weaken the competitive position of the Dutch pig sector (van Berkum *et al.*, 2002).

Given the changes in competitive position of the Dutch pig sector as outlined above, van Berkum *et al.* (2002) expect that the size of the pig sector could stabilise at maximum at about 70-75% of the size in the mid 1990s. This size in the future crucially depends on future costs of manure disposal, partially determined by developments in the dairy sector (see below). As opposed to the arable and dairy sectors, the largely landless pig sector is not likely to be eligible for direct payments related to pig farmers' contributions to societal goals other than food production.

Dairy sector

Implementation of Agenda 2000 did not affect optimal configuration of the dairy sector, but reduced labour income by 12%. Reductions in labour income as induced by Agenda 2000 reinforce on-going developments in the dairy sector. One strategy followed by dairy farmers is to reduce costs per kg milk, e.g. by increasing the scale of production, increasing milk production per ha and adoption of zero-grazing systems (Besseling *et al.*, 2001). Other dairy farmers may follow a strategy aimed at increasing revenues per unit costs, e.g. by converting to organic production or intensify participation in subsidised farm-nature management.

Currently, the milk quota system limits expansion of the dairy sector. If the EU decides to abolish the system, the Dutch dairy sector is likely to expand (Berkhout *et al.*, 2002, based on model calculations). Assuming a milk price reduction twice that anticipated in Agenda 2000 - 30% instead of 15 -, compensated by a two times higher direct payment per ton of milk quota - € 50 per ton milk instead of € 25 -, the increase in milk production may be as large as 40% (Berkhout *et al.*, 2002). This increase is smaller when compensatory payments only cover the current national milk quota, excluding the additional milk produced after milk quota abolition. Expansion of the dairy sector is at the expense of other agricultural sectors and reflects the favourable competitive position of the dairy sector - largely derived from direct payments per ton of milk quota - relative to the arable and landless animal sectors. While it seems unlikely that the quota system will be abolished at a milk price and income support as high as assumed by Berkhout *et al.* (*op. cit.*), the model calculations illustrate how coupled direct income payments guide farmers' decisions to increase production.

Implementing Full Liberalisation in the dairy sector, maximum labour income, solely derived from milk production, becomes negative. This suggests that profitable milk production without direct payments would not be possible. To what extent this finding holds in reality depends on the possibilities to reduce costs per kg milk or increase revenues per unit costs, and on the magnitude of direct payments granted to the dairy sector. Considerably reduced milk prices, combined with abolishment of the milk quota system is likely to induce adoption of production activities in the dairy sector that are currently not practised ('induced innovation'), neither represented in the MGLP model. Under a Full Liberalisation scenario, the bulk of milk production in the Netherlands is likely to be produced in feedlot-like dairy farms, taking full advantage of economies of scale with at least 200 highly productive dairy cows in zero grazing systems (Besseling *et al.*, 2001; van Eck *et al.*, 1996). Such farms have partly or fully contracted out the cultivation of feed crops - including grass - and the breeding of young stock. Manure is disposed of by concluding manure contracts with feed-producing farms. When combined with food crop production, contracting out the cultivation of feed crops may result in the widening of crop rotations.

Mixed farming systems

As outlined above, one of the consequences of market liberalisation in the long term could be the appearance of large-scale dairy farms, exchanging manure for feeds with large-scale arable farms. At regional scale, such farming systems are plainly mixed farming systems, and - depending on the specifications of arrangements between the farms - potentially combine all of the advantages of mixed farming systems as quantified in previous chapters, including the widening of arable crop rotations and the utilisation of the non-restrictive character of the MINAS system in arable cropping systems (Chapter 5).

7.6.2 Consequences for agricultural biodiversity and environment

Undoubtedly, any future CAP reform will continue to substitute market price support by direct payments. A 'radical' reform - such as Full Liberalisation - is however unlikely, as there are many powerful influences defending the CAP in its current form. Irrespective of the details of future reforms, these are likely to reinforce further scaling-up and specialisation of farming systems across Europe, as is illustrated above for the Netherlands. Such farming systems are not necessarily more environmentally damaging, but have negative effects on agricultural biodiversity. The preservation of extensive and biodiversity-supporting farming systems will become more difficult and increasingly relies on EU interventions (Dixon, 1997). Under the same CAP-regime, development paths will differ among EU countries, as national perspectives and objectives for the rural areas differ. For example, maintaining family farms is a priority in some EU countries, while in others, such as the Netherlands, an 'efficient', export-oriented and competitive agricultural sector is the priority. Such traditional differences in national perspectives among countries are likely also existent with reference to multifunctional farming systems.

From a nature conservation perspective the CAP needs to be changed (Dixon, 1997). Key elements of reform should include the full internalisation of environmental costs and benefits of agricultural production, and the granting of subsidies only for achieving wider social and environmental objectives, rather than being coupled to agricultural commodities and crop areas (Pretty *et al.*, 2001; Dixon, 1997). An example could be Switzerland, where farmers have to meet five minimum conditions - the so-called 'ecological standard' of performance - in order to receive direct payments (Pretty *et al.*, 2001):

(1) provide evidence of balanced use of nutrients with fertiliser matched to crop demands;
(2) soils must be protected from erosion and erosive crops can only be cultivated in rotation with meadows and green manures;
(3) at least 7% of the farm area must be allocated to species diversity protection through unfertilised meadows, hedgerows or orchards;
(4) use of diverse crop rotations;
(5) pesticide use has to be reduced to established risk levels.

7.6.3 Outlook

In July 2002, EU Agriculture Commissioner Franz Fishler presented a proposal for further CAP reform as part of the mid-term review of Agenda 2000 (CEC, 2002). The proposal identifies discrepancies in many areas between the objectives of the CAP set in Agenda 2000, and the capacity of Agenda 2000 to realise these objectives, including (1) considerable remaining uncertainties as to whether prices of some products have been sufficiently reduced to comply with WTO regulations and (2) discouraging farmers to adopt more environmental-friendly production methods, resulting from the scale of support still provided through prices and product-specific payments. Proposed adjustments for the arable sector, as far as relevant here, include the introduction of compulsory long-term non-rotational set-aside - replacing the current semi-compulsory rotational set-aside - and an extra 5% reduction in the intervention price of cereals, compensated by an increase in area payments. For the dairy sector, a number of options are put forward, including implementation of Agenda 2000 reforms earlier than 2005/2006 and increasing or removing milk quotas, combined with further intervention price reductions. Within a longer time horizon, Fishler proposes to "accomplish the final step in the shift from support from product to producer" by introducing a system of single income payments per farm. This system should eventually replace all existing direct payments. The payment per farm, fully decoupled from products and crop areas, is to be based on historical direct payments. After implementation of the system, farmers will have complete flexibility to produce anything they want, but payment will be conditional on compliance with codes of good agricultural practice.

A major reform proposal is to reinforce incentives promoting the adoption of farming methods that contribute to realisation of societal objectives other than food production, i.e. go beyond codes of good agricultural practice. This is to be accomplished by stepwise reducing direct payments granted to farms receiving more than € 5 000. The stepwise reduction is introduced from 2004 onwards, to reach a maximum reduction of 20% by 2010 (in EU jargon: compulsory modulation). The budget generated by modulation has to be invested by Member States in their rural development programmes, including programmes designed to promote farming methods beyond codes of good agricultural practice. The amounts will be allocated to Member States on the basis of agricultural area, agricultural employment and a prosperity criterion, allowing redistribution of payments from intensive cereal and livestock producing countries to poorer and more extensive producing countries. In the Netherlands, 73 500 farmers received direct payments in 2001, of which 17 500 (25%) received payments exceeding € 5 000 (Dokter, 2002). The latter category will be subject to modulation.

Should all proposals of the mid-term review be agreed by the EU Heads of States unaltered - which is highly doubtful -, EU farmers will have to weigh production-oriented farming under compliance with codes of good agricultural practice against farming under eligibility of receiving additional direct payments for providing services beyond codes of good agricultural practice. This has been so in the recent past as well, with the result that the majority of Dutch farmers chose for production-oriented farming. It seems not likely that this will change in the near future, as the mid-term review proposals do not drastically change the profitability of production-oriented farming for 75% of Dutch farms, because these are not subject to modulation. The mid-term review however increases available budgets for farming beyond codes of good agricultural practice, which potentially increases its adoption in practice. The mid-term review also meets some of the criticism expressed by non-governmental development agencies. However, it remains to be seen to what extent the proposals actually reach the stage of implementation. European farmer's organisations strongly oppose the mid-term review proposals and do not want not to proceed beyond Agenda 2000. The reform of the common market organisation for sugar is scheduled for 2003.

7.7 Conclusions

➢ Agenda 2000 does not affect optimal configuration of farming systems, but reduces labour income from arable cropping and dairy farming activities and increases labour income from pig production.

➢ Agenda 2000 is not likely to induce drastic changes in land use in the Netherlands other than resulting from autonomous developments.

➢ Full Liberalisation results in large reductions in labour income from arable cropping and dairy farming activities.

➢ Full Liberalisation, enabling remuneration of farmers for providing services beyond codes of good agricultural practice in a budget-neutral way, is likely associated with considerable changes in agricultural land use in the Netherlands. Farms will roughly be divided in two main categories:
   - large-scale, highly specialised farms focussing on bulk production for world markets, potentially incorporating all advantages of mixed farming systems;
   - farms combining food production with contributions to other societal goals.

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CHAPTER 8

General discussion

8.1 Recapitulation

Growing awareness of the unsustainability of some features of current Dutch agricultural production systems has caused renewed interest in mixed farming systems, mainly reflected in increased research efforts and with this thesis as one of the results. The research described in this thesis is the result of an iterative process. Originally, it was intended to contribute to the exploration and design of mixed farming systems in general and the 'integrated' prototype mixed farming system at the A.P. Minderhoudhoeve in particular. However, in the course of the process it was decided to shift emphasis towards analysing differences in environmental and economic performance between specialised and mixed farming systems and towards policy analysis. Two observations explain the chosen directions. First, according to Lantinga & Rabbinge (1996), the main advantages of mixed farming systems are:

- higher nutrient use efficiency and reduction of use of external inputs through (i) use of home-grown concentrates (less purchased concentrates), (ii) more efficient application of animal manure, and (iii) widening the crop rotation (less pesticide use and higher yields due to less problems with soil-borne pests and diseases);
- better utilisation of available labour and spreading of income risks.

The advantages attributed to mixed farming systems are not unambiguous, because they may also be realised in specialised farming systems and are partially conflicting[1]. Hence, a systematic quantification of differences in environmental and economic performance between specialised and mixed farming systems was considered useful, to contribute to the discussion on the desirability of re-introducing mixed farming systems in the Netherlands.
Secondly, it was perceived that in the coming decade Dutch farming systems face major changes in the policy environment in which they are embedded, related to changes in the Dutch manure policy and to reforms of the Common Agricultural Policy (CAP). Analysing the impact of the changed policy environment on farming systems and simultaneously assessing the efficacy of policies in attaining the policy objectives was considered of interest to the

[1] Increasing the use of home-grown concentrates conflicts with increasing nutrient use efficiencies.

agricultural community and policy makers. Therefore, the objectives of the research were to:

(1) systematically quantify agronomic-technical differences between specialised and mixed farming systems;
(2) systematically quantify differences in environmental and economic performance between specialised and mixed farming systems in current and conceivable future policy environments, as resulting from the agronomic-technical differences quantified under (1);
(3) test the efficacy of anticipated policies in attaining the pursued policy objectives;
(4) when required, formulate alternative policy scenarios that better effectuate the pursued objectives.

Modelling, in principle, allows a transparent and consistent evaluation of a large number and wide diversity of farming systems and allows *ex ante* assessment of the impact of changes in policy environment on these farming systems. The multiple goal linear programming (MGLP) model developed in this study optimises the configuration of specialised or mixed farming systems, subject to a set of constraints, to one of a set of defined objectives, selecting from a large set of agricultural activities. MGLP bridges the gap between basic and applied sciences and integrates bio-physical and socio-economic sciences (van Ittersum & Rabbinge, 1997). As such, it is a useful tool in bridging the gap between the theory of the sustainability paradigm and agricultural practice (von Wirén-Lehr, 2001).

This final Chapter 8 synthesises and reflects on the findings in previous chapters. Section 8.2 focuses on objectives (1) and (2) and Section 8.3 on objectives (3) and (4). Some general comments on the methodology are given in Section 8.4. Section 8.5 summarises the main conclusions of the study.

8.2 Comparing specialised and mixed farming systems

8.2.1 Definition of specialised and mixed farming systems

This study defined regionally specialised farming systems as combinations of dairy farming, arable cropping and landless pig production. Regionally specialised farming systems were characterised by two key features, distinguishing them from regionally mixed farming systems. First, each of the three building blocks of a regionally specialised farming system functioned as an independent economic unit. This was accomplished by pricing all transfers of products and by-products among the three agricultural sectors within the region. Naturally, sales to the external market were also priced. Second key feature was the permanent physical separation of land used for dairy farming from that used for arable cropping.

A regionally mixed farming system was defined by merging the economic units to form one new economic unit and by integrating land use of the specialised dairy farming system and the specialised arable farming system. Hence, in a regionally mixed farming system, all price tags attached to transfers of products and by-products among the three sectors were removed, and one new rotation was formed, characterised by regular alternation of arable crops and leys.

8.2.2 Differences between specialised and mixed farming systems

Differences in environmental and economic performance between specialised and mixed farming systems originated from agronomic-technical, organisational and institutional differences.

Agronomic-technical differences were quantified in Chapters 2, 3 and 4, derived from the integration of land use in the mixed farming system. Compared to specialised farming systems and depending on the relative lengths of the arable and grassland phases, integration of land use in mixed farming systems resulted in lower cropping frequencies, higher mineralisation rates under arable crops and lower mineralisation rates under grassland. Lower cropping frequencies were assumed to result in lower incidence levels of soil-borne pests and diseases and for some crops, notably economically important ones, in higher yields per ha.

Organisational differences resulted from the exchange of labour and machines in mixed farming systems, reducing the need to hire external labour, thus reducing costs. Quantifying organisational differences requires specification of farm size, labour availability, machine inventory, etc. Such specifications, and hence also organisational differences, were only considered in Chapter 2.

Institutionally-based differences came to the fore in calculations with the MGLP model in Chapters 5 through 7 and were related to Dutch manure policy regulations, i.e. MINAS and the manure contract system. The impact of MINAS on regional labour income was different for specialised and mixed farming systems. In specialised farming systems, MINAS surpluses in the arable sector were always appreciably lower than levy-free surpluses. At regional scale, the large gaps between MINAS surpluses and levy-free surpluses in the arable sector could not be utilised in specialised farming systems. This was different in mixed farming systems: as only one combined MINAS balance is calculated, the non-restrictive character of the MINAS system in arable cropping could be entirely utilised and was allocated to the most profitable activity, dairy farming. This advantage of mixed farming systems applies at least in mixed farming systems organised at farm scale. Whether it also applies to mixed farming systems organised at regional scale depends on the juridical details of the MINAS system and is not known by the author. Anonymous (2002) suggests that the advantage indeed would also apply in mixed farming systems organised at regional scale.

A second institutionally-based difference between specialised and mixed farming systems was introduced by assuming a 50% rate of acceptance of manure in the specialised arable sector, limiting manure-N use in that sector to 85 kg ha^{-1}. In mixed farming, no such limit to manure-N use in arable cropping is applied. Consequently, total regional manure-N production in mixed farming systems can attain a higher value than in specialised farming systems, contributing to higher labour income. The choice to limit manure-N use in the specialised arable sector to 50% of the legally permitted quantity is arbitrary, but based on a survey among arable farmers (Hees & Hin, 2000).

Results presented in this thesis suggest that, from an economic perspective, mixed farming is more attractive than specialised farming. These results are in contradiction with the long-term negative trend in the number of mixed farms in the Netherlands. This conflict between model results and 'the real world' suggests that the results represent too optimistic a picture, and/or that statistics as such on the number of mixed farms only show part of the picture.

A theoretical framework explaining the 'appearance' of farming systems was shortly addressed in Chapter 2. In this framework, farming systems are viewed as being subject to two opposite forces: differentiating forces and integrating forces. Differentiating forces promote specialisation, leaving few or only one cropping or livestock system(s) at the farm. Integrating forces lead to farms in which several cropping or livestock system(s) are combined. An important differentiating force is represented by cost savings associated with large scale

production (further denoted economies of scale). Since the introduction in agriculture of labour-saving technologies with high fixed costs, combined with guaranteed product prices, this force has been dominant and largely explains the rapid specialisation of Dutch agriculture since the 1950s. Economies of scale have not been considered in this study. Rationale is that the competitive disadvantage of mixed farming relative to specialised farming due to economies of scale can be avoided in mixed farming systems organised at regional scale. In such mixed farming systems, the economic benefits of specialisation at farm level can be combined with the benefits of mixing at regional scale. However, limitations to mixed farming systems at regional scale still remain. Firstly, mixed farming systems require farmers to sacrifice part of their independence and accept the complexity of arrangements needed to organise regionally mixed farming systems. In general, loss of independence and complexity of arrangements increase with the intensity of co-operation between farms. Secondly, from a national perspective, scope for organising mixed farming systems at regional scale will vary strongly among regions. In many regions of the Netherlands, land use is unevenly distributed over agricultural sectors. This is related to historical backgrounds (e.g. dominance of arable cropping in Flevoland) or is imposed by the physical environment (e.g. dominance of dairy farming in the peat areas in the west of the country).
While the number of mixed farms has shown a decreasing trend, co-operation between neighbouring farms is a common phenomenon (e.g. Hendriks & Oomen, 2000; Anonymous, 1995). In most cases, these forms of co-operation are restricted to exchange of manure for feed or exchange of land (i.e. the cultivation of an arable crop, often seed or ware potato or flower bulb crops, after grass or silage maize cultivation at dairy farms), leaving the co-operating economic units intact. Such common forms of 'mixing' at regional scale are not expressed in statistical data. As shown in Chapter 5, manure policy regulations in mixed farming systems allow much higher production levels than in specialised farming systems. This implies that manure policy regulations could act as a new integrating force.

8.2.3 Environmental performance

Results in this study show that NO_3-N-losses per ha in mixed farming systems potentially attain higher values than in specialised farming systems (compare

Figures 5.1 and 5.4). This will in part be due to the fact that the intensities of the associated mixed farming systems were much higher than those of the specialised farming systems. Therefore, an additional optimisation is performed here in a 'quick-scan fashion' in which land use - i.e. crop and grassland areas, regional milk production and grazing system - of the mixed and specialised farming are equated. Accordingly, a regionally specialised farming system and a regionally mixed farming system are defined that realise about equal outputs in terms of crop products and milk quantity. After maximising labour income, the results show that the difference in regional NO_3-N leaching between the mixed farming system and the specialised farming system is small (7 kg NO_3-N per ha). A comparison of a specialised and mixed farming system with equated land use was also reported in Chapter 2, *inter alia* focussing on nutrient balances. Also there, differences in nutrient surpluses between specialised and mixed farming were small.

A typical feature of mixed farming systems is the regular alternation of leys and arable crops. The ley phase is associated with an increase in organic matter content and the arable phase with a decrease. In specialised farming systems such alternation is absent. This difference in land use between specialised and mixed farming systems has consequences for organic matter management in the two farming systems. Compensating annual mineralisation of organic matter in specialised farming systems in the model required autumn application of manure in the arable crop rotation and in continuously cropped maize. In mixed farming systems, the necessity to apply manure to arable crops for the maintenance of organic matter levels is absent, provided the grassland phase is long enough to compensate for the decline in organic matter content during the arable phase. Whether this constitutes a systematic environmental advantage of mixed farming systems depends on the N-losses associated with the ploughing of leys, as compared to N-losses associated with autumn application of manure to arable crops and maize. The approach followed in this study to quantify N-losses associated with the ploughing of leys in mixed farming systems is considered too simple for firm conclusions. Note that if timing of manure application in specialised farming systems can be shifted from autumn to spring, a systematic environmental advantage of mixed farming systems, resulting from better manure-N-utilisation, intuitively seems absent.

Scope for reduced pesticide use in mixed farming systems on clay soils, due to lower pest and disease incidence levels and to potentially reduced weed populations, was qualitatively assessed in Chapter 2. The body of evidence in literature supporting such scope was considered insufficient for firm conclusions. This was one of the reasons for not further considering pesticide use in the MGLP model.

The overall picture emerging from this study is that agronomic-technical differences between specialised and mixed farming systems do not result in systematic differences in environmental impact in terms of nutrient emissions and pesticide use per ha. On the contrary, as mixed farming systems are less constrained by manure policy regulations, N-emissions per ha are potentially higher.

8.3 The role of manure policy regulations in reducing N-emissions

8.3.1 Efficacy

The core instruments of the Dutch manure policy are the MINAS system and the manure contract system. Both systems operate at the scale of individual farms. MINAS is the instrument to restrict nutrient emissions from farms to the external environment, based on a farm gate nutrient balance approach. MINAS incorporates the 'polluter pays' principle by imposing a levy if N and/or P surpluses exceed levy-free surpluses[2]. The magnitudes of the levies are set such that they should be prohibitive, as the governments' intention with MINAS is not to collect money, but to stimulate farmers to adapt farm management to reduce nutrient surpluses. The Dutch government claims that if farms realise MINAS surpluses below the levy-free surpluses foreseen for 2003, nutrient surpluses of these farms are such that the objectives of the Nitrate Directive are met.

An important feature of the Nitrate Directive is that it specifies the maximum amount of animal manure that can be applied to farmland each year. This

[2] Levy-free surpluses foreseen for clay soils for the year 2003 are 180 kg N ha^{-1} grassland, 100 kg N ha^{-1} arable land and 9 kg P ha^{-1} grassland plus arable land. These values have been used throughout this study. The values applicable in the year 2002 were 220, 150 and 11 kg ha^{-1}, respectively. Whether the planned reduction of 2002-values to 2003-values is actually enforced is unsure, and to be decided upon by Dutch Parliament in the second half of 2002.

regulation has been implemented in Dutch agriculture via the manure contract system. In this system, manure production at livestock farms is calculated in a standardised way by multiplication of default values for annual N excretion per animal with the number of animals present at the farm. Livestock farms producing manure in excess of 170 kg N per ha arable land plus 250 kg per ha grassland are obliged to formally transfer the excess to arable farmers (or other 'consumers')[3]. Current Dutch manure policy permits livestock farms to deviate from this regulation, by allowing farms to produce and apply manure in excess of the stipulated rates, provided their MINAS surpluses do not exceed levy-free surpluses. Such livestock farms conclude 'manure contracts on paper' with 'consumers', but are not obliged to actually transfer the excess manure to the 'consumer'. If either the MINAS N surplus or the MINAS P surplus exceeds the levy-free surplus, actual transfer is obliged, which is associated with manure disposal costs. The manure contract system thus serves as a stimulus for livestock farmers to realise MINAS surpluses below the levy-free surpluses.
The consequence of the Dutch interpretation of Nitrate Directive regulations is that standardised manure production *at national scale* does not exceed 170 kg N per ha arable land plus 250 kg per ha grassland, but this is not necessarily so at *farm scale*. The Dutch interpretation is not fully in accordance with the 170/250-regulation in the Nitrate Directive, which is formulated at farm scale. The Dutch interpretation is therefore coined here a 'flexible interpretation of Nitrate Directive regulations', as opposed to the EU's 'strict regime of compliance to Nitrate Directive regulations', i.e. at farm scale. The 'flexible interpretation' reflects the way of thinking of Dutch policy makers, who consider MINAS as the regulating instrument to comply with Nitrate Directive objectives at farm scale, and the manure contract system as a helpful, but sometimes redundant tool. The ultimate goal in the view of Dutch policy makers is the realisation of MINAS surpluses below levy-free surpluses at each farm, irrespective of manure production at the farm. In reducing NO_3-N emission, this policy view clearly puts the stress on the MINAS system.
The Dutch manure policy is beset with four major uncertainties. These refer to (1) the planned reduction of 2002 levy-free surpluses to values for 2003, (2) the acceptance by the EU of the MINAS system as the regulating instrument to comply with the objectives of the Nitrate Directive, (3) the acceptance by the EU

[3] This is under the assumption that the derogation request, as under consideration with the European Commission, will be granted.

of the Dutch 'flexible interpretation' of one of the Nitrate Directive regulations and (4) the decision on the Dutch derogation request as submitted to the European Commission.

The objective of the Nitrate Directive is to reduce water pollution caused or induced by nitrates from agricultural sources, and to prevent further such pollution. To what extent does the MINAS system contribute to realisation of these objectives? The results presented in this thesis and data from literature show that the effect of MINAS strongly varies among sectors and farming systems. In the arable sector, MINAS-2003 (i.e. MINAS incorporating the levy-free surpluses foreseen for the year 2003) will certainly top off excessive manure use at arable farms, but leaves nutrient management at 50-60% of the arable farms unaffected, as these farms already in 1999/2000 realised MINAS surpluses below the levy-free surpluses for 2003 (de Hoop, 2002). Moreover, MINAS-2003 still leaves room for inefficient use of considerable quantities of manure-N (this study; van der Schoot & van Dijk, 1999). The impact of MINAS in the dairy sector is larger: based on 1999/2000 nutrient balances, 90% of a representative sample of specialised dairy farms has MINAS surpluses in excess of the levy-free surpluses, had MINAS-2003 applied (de Hoop, 2002). Consequently, almost all specialised dairy farms will have to take measures before the year 2003 to avoid having to pay levies or high costs for manure disposal. Hence, based on 1999/2000 nutrient balances in the arable and dairy sector, MINAS-2003 is likely to induce a reduction in NO_3-N emission. Based on model calculations at national scale, Oenema *et al.* (2002) estimate that introduction of MINAS-2003 reduces NO_3-N emission from agriculture to surface waters by 23-33% (reference year 1985). The policy objective as based on the Rhine Action Programme and the North Sea Action Programme is a 50% reduction (Anonymous, 1989).

If Dutch Parliament decides not to enforce the 2003 levy-free surpluses, hence to adhere to those of 2002, less farms will be stimulated to reduce nutrient surpluses. In that situation, 75% of arable farms and 30% of dairy farms are not affected by the MINAS system, based on their 1999/2000 nutrient balances (de Hoop, 2002). Oenema *et al.* (2002) estimate that introduction of MINAS-2002 reduces NO_3-N emission from agriculture to surface waters by 15-25%.

The 'flexible interpretation' of one of the Nitrate Directive regulations by the Dutch government allows a higher standardised national manure production than would have been the case under a regime of strict compliance, as it reduces the supply of manure on the manure market and hence reduces the costs of manure disposal for livestock farms, leaving more livestock farms engaged in production. It is expected that under MINAS-2003, 75% of dairy farms, although producing manure in excess of 170 kg N per ha arable land plus 250 kg N per ha grassland, can apply their manure within the farm, because their MINAS surpluses are lower than levy-free surpluses[4] (Bruins, 2002). Landless livestock farms, on the other hand, are even under the 'flexible interpretation' of the Nitrate Directive confronted with high costs to dispose of their manure.

A regime of strict compliance with Nitrate Directive regulations, in which manure in excess of 170 kg N per ha arable land plus 250 kg N per ha grassland is either not produced or transferred to 'consumers' of manure, will have a strong impact on Dutch agriculture. In the short term, it will result in a substantial increase in manure supply on the manure market and is likely associated with a further increase in manure disposal costs, particularly affecting landless livestock farms or farms with limited land holdings. In the longer term, an equilibrium between manure production and manure application opportunities will develop, in which national manure production is expectedly lower than under a regime of 'flexible interpretation' of Nitrate Directive regulations. It is difficult to assess the consequences for NO_3-N leaching. One important factor is the price of manure disposal, which might be positive or negative. As long as 'producers' of manure have to pay the 'consumers' (i.e. positive price, the current situation), an extra incentive for arable farmers exists to use manure-N in crop fertilisation, with associated increased NO_3-N leaching risks. The incentive for dairy farmers is however to fully or partly substitute maize cultivation by grass cultivation, which might be associated with reductions in NO_3-N leaching and labour income. In the reversed situation, if 'producers' of manure are paid by 'consumers', the use of manure-N in arable cropping is likely to decrease, compared to the current situation, likely associated with a reduction in NO_3-N leaching. In this situation, the incentive for dairy farmers to substitute maize cultivation by grass cultivation is weaker or even absent, which in turn may increase NO_3-N leaching risks.

The consequences of a rejection of the derogation request by the European Commission are similar to those described above under a strict regime and

[4] This suggests that many dairy farms are expected to have taken measures between 1999/2000 and 2003 to avoid paying MINAS levies.

granting of the derogation request. General trends will be a substantial increase in manure disposal costs in the short term and attainment of a new equilibrium in the longer term, characterised by lower national manure production. If the derogation request is not granted, there is no incentive for dairy farmers to substitute maize cultivation by grass. Rejection of the derogation request could occur under (1) permission of a flexible regime of compliance with the Nitrate Directive or (2) a strict regime of compliance. In the latter situation, standardised national manure production in the longer term is expectedly at the lowest of all scenario's. Presumably, NO_3-N leaching is also at the lowest, because databases of livestock density, nutrient surpluses and emissions across Europe reveal a negative relationship between the presence of animals and environmental quality, although the robustness of this relationship is questionable (Schröder *et al.*, 2002).

In its manure policy, the Dutch government finds itself in an unenviable position. On the one hand, there is the European Commission that is to be convinced of the efficacy of the MINAS system in sufficiently improving groundwater and surface water quality, with legal infringement procedures as unattractive outlook in case of non-compliance. On the other hand, there are farmers' organisations in the Netherlands that 'do not like MINAS' and oppose against any further tightening of the manure policy regulations applicable in the year 2002 (Anonymous, 2002). While not yet having been able to convince the European Commission of the efficacy of the MINAS system, the Dutch government submitted a derogation request for grassland to the Commission and, strictly speaking, partly neglects the Nitrate Directive, given the Dutch 'flexible interpretation' of one of its crucial regulations. In this situation, a wise strategy might be to develop additional policy instruments with two specifications: (1) specifically targeted to reducing NO_3-N loss and (2) outlook on farmers' support.

8.3.2 Means-oriented regulations?

A strength of the MINAS system is that it is based on a whole-farm balance approach, in which nutrient surplus is calculated as total inputs minus total outputs. Nutrient surpluses are generally considered better indicators of losses than e.g. limits to manure application per ha land (Schröder *et al*., 2002), which is the selected indicator by the European Commission. Moreover, the MINAS system provides a framework for regulation of not only N-emissions, but also of ongoing P-accumulation and emissions, which in the future may pose serious environmental threats.

A weakness of MINAS identified in this study is that it still allows agricultural practices that are associated with relatively high leaching losses. Chapter 6 concluded therefore that if MINAS is to substantially reduce NO_3-N loss from agriculture in all situations, levy-free N surpluses should be differentiated according to farming system design, complicating the feasibility and enforceability of the system. Effective accompanying instruments in Dutch manure policy could thus be targeted means-oriented regulations, specifically aimed at reducing NO_3-N leaching. Today, pleading for means-oriented regulations in agriculture is like swearing in church. Note, however, that two recent 'innovations' in agriculture have exactly been achieved via means-oriented regulations: the obligation to apply manure using low-emission techniques and the obligation to cover manure storages. Low-emission techniques and covering manure storages are now the norm. Another argument in favour of accompanying means-oriented regulations is provided by the limited adoption of 'integrated arable farming systems' by farmers, despite these systems combining environmental and financial benefits, while being technically feasible (de Buck *et al.*, 2000).

Agricultural practices associated with high leaching losses identified in this study include autumn application of large quantities of animal manure to arable crops, including maize. Agri-environmental policies should stimulate farmers to refrain from these practices. In the current manure policy environment, such stimuli are weak. In this respect it is worth noting that the national farmers's organisation and the Ministries of Agriculture and Environment have signed a position statement in which they agreed to maintain 'sufficient' - which is not further specified - manure application opportunities in the clay areas in the Netherlands (Anonymous, 2000), to avoid a further increase in manure disposal costs. Hence, the absence of these stimuli could be part of a policy not to frustrate the acceptance of animal manure by arable farmers.

Two measures potentially reduce the N-loss associated with application of manure in autumn: (1) combining manure application in autumn with the cultivation of a catch crop, while restricting the application rate to the uptake capacity of the catch crop or (2) spring application of manure. Farmers' considerations in this respect include the following:

- effectively reducing NO_3-N loss by combining autumn manure application with catch crop cultivation, limits manure application rates at farm scale, reducing revenues from the use of manure;
- spring application entails more risks than autumn application, because it requires critical tuning of weather and soil conditions, on-farm tasks and the availability of contract-labour, hired for manure application;
- spring application entails more risks than autumn application, because the N-fertiliser value is uncertain, resulting in reduced yields in case of N shortages or in inferior product quality in case of over-supply of N.

One option to stimulate the adoption of the two measures is to further reduce levy-free N surpluses. However, as shown in Chapter 6, the levy-free N surplus should then be considerably reduced, undoubtedly not much supported by farmers. Moreover, it is a rather negative, penalising approach.
A good case can be made to qualify autumn-application of animal manure without catch crop cultivation as a wasting and polluting activity, conflicting with codes of good agricultural practice. A stimulating policy should convince farmers of this, motivating them to refrain from the activity. Elements of such a policy could include the discouragement of autumn-application of manure, for example by restricting manure-N-input at arable farms employing autumn application to a value corresponding with N-uptake capacity of cultivated catch crops, and the promotion of spring application, by permitting higher manure-N-input at arable farms under spring application. As shown by Dekking (2000), spring application of manure on clay soils is technically feasible and results in financial gains, compared to using only mineral fertilisers. Hence, in addition to stimulating the implementation of good agricultural practice - which will be much appreciated by the European Commission -, a policy promoting its adoption in practice may possibly meet more support from farmers.

8.4 Methodological considerations

The purposes of the study determine the agricultural activities that should be included in the MGLP model. If one of the purposes is to explore future options for land use, it is important to 'look ahead', i.e. to include innovative activities currently in the R&D pipeline, next to currently practised activities. If one of the purposes is to evaluate near-future policies in attaining the pursued policy objectives and analyse the 'behaviour' of farming systems under these policies - as in this study -, emphasis should be on currently practised activities. Linked to this is the rather problem-oriented character of the study, rather than presenting promising 'innovative' solutions to problems in agriculture. The exclusion of 'innovative' activities in this study might reduce the 'window of opportunities'. Note that technological 'innovations', such as row fertilisation, catch crop cultivation and spring application of manure, have been available for a number of years, but that adoption in practice is still limited. Adoption in commercial farming is constrained by farmers' perceptions of risks associated with these 'innovations' (de Buck, 2001), often related to their higher costs.

Farmers' explicit and implicit goals are expressed in their behaviour, which has a strong impact on the characteristics of farming systems. In fact, the behaviour of farmers in future policy environments is crucial in determining whether we will see a revival of mixed farming systems. However, interactions between behaviour and design of farming systems have hardly been considered in this study. Hence, in addition to insights from normative, model-based analyses as presented in this thesis, knowledge of farmers' behaviour is essential in understanding development paths of farming systems.

A linear programming model may not take into account all the objectives and constraints that are important for stakeholders. Many issues can not be quantified satisfactorily and the calculated optimal solution therefore is not necessarily the best solution in the real world. Solutions that better reflect the variance in stakeholders' objectives may be found in a set of nearly optimal solutions, in which the value of the objective is allowed to deviate slightly from that in the optimal solution. Nearly optimal solutions are all 'good' in terms of the objective, but can mutually differ considerably in terms of activities. A framework for generating and presenting sets of nearly optimal solutions has been described by Makowski *et al.* (1998; 1999).

The added value of MGLP-studies such as this study is that they integrate knowledge of different disciplines in a transparent, coherent and consistent framework. This integration should result in 'new' insights into the behaviour of farming systems. Whether this study succeeded in revealing such new insights is left to the discretion of the reader.

8.5 Conclusions

Chapter 2:

- Merging a specialised arable farm and a specialised dairy farm with specifications as in Chapter 2 to one mixed farm, exchanging land, labour and machinery,
  - increases labour income per ha by 25%, attributable to higher yields per ha of the arable crops and to a better utilisation of available labour;
  - does not have environmental effects, as measured from nutrient balances and pesticide use.

Chapter 5:

- Manure policy regulations foreseen for the year 2003 allow farming systems characterised by the production of large quantities of manure-N and subsequent inefficient use of that N in maize and arable crops.

- On a regional scale, maximum labour income in mixed farming systems is much higher than in specialised farming systems. Higher labour income arises from a different impact of manure policy regulations in mixed farming, allowing a much higher milk production than in specialised farming.

Chapter 6:

- A gap exists between levy-free N surpluses foreseen for 2003 and levy-free N surpluses required to attain the standard for NO_3-N leaching. This gap is larger as arable cropping and/or maize cultivation are more important in terms of area use and increases in the order dairy farming, mixed farming and arable cropping. Bridging this gap has limited effects on labour income in all situations.

- If MINAS is to substantially reduce NO_3-N loss from agriculture, levy-free N surpluses should be differentiated according to farming system, grazing system and the ratio of grassland and arable land. Such a differentiation is likely to severely complicate the feasibility and enforceability of the MINAS system.

- Inclusion of P in mineral fertiliser as input term in the MINAS balance is an effective measure to reduce NO_3-N loss in the dairy sector, as it results in a more balanced distribution of slurry over maize and grassland.

- Means-oriented regulations, specifically aimed at reducing NO_3-N leaching, are useful additional instruments in Dutch manure policy.

Chapter 7:

- Agenda 2000 does not affect optimal design of farming systems, but reduces labour income from arable cropping and dairy farming activities and increases labour income from pig production.

- Agenda 2000 is not likely to induce drastic changes in land use in the Netherlands other than resulting from autonomous developments.

- Full Liberalisation results in large reductions in labour income from arable cropping and dairy farming activities.

- Full Liberalisation, enabling remuneration of farmers for providing services beyond codes of good agricultural practice in a budget-neutral way, is likely associated with considerable changes in agricultural land use in the Netherlands. Farms will roughly be divided in two main categories:
  - large-scale, highly specialised farms focussing on bulk production, potentially incorporating all advantages of mixed farming systems;
  - farms combining food production with contributions to other societal goals.

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Summary

Growing awareness of the unsustainability of some features of current Dutch agricultural production systems also caused renewed interest in mixed farming systems. Rationale is that mixed farming systems supposedly have some advantages over specialised farming systems, including higher nutrient use efficiencies, reduced use of external inputs, better utilisation of available labour and spreading of income risks. Most important mechanisms underlying these expected benefits are the use of on-farm produced concentrates, more efficient use of animal manure and wider crop rotations. The advantages attributed to mixed farming systems are not unambiguous and may also be realised in specialised farming systems. Hence, a systematic quantification of differences in environmental and economic performance between specialised and mixed farming systems was considered a useful contribution to the discussion on the desirability of re-introducing mixed farming systems in the Netherlands. Inspired by major changes in the policy environment awaiting Dutch farming systems in the near-future, a second focal point of this thesis is policy analysis. With regard to these policies, numerous 'what if' questions can be posed. Such questions addressed in this thesis consider the optimal configuration of specialised and mixed farming systems under Dutch manure policy regulations, the efficacy of these regulations in reducing emissions and the impact of moderate and more drastic reforms of the European Union's Common Agricultural Policy (CAP) on optimal configuration of specialised and mixed farming systems. The main objectives of the research described in this thesis were to:

(1) systematically quantify agronomic-technical differences between specialised and mixed farming systems;
(2) systematically quantify differences in environmental and economic performance between specialised and mixed farming systems in current and conceivable future policy environments, as resulting from the agronomic-technical differences quantified under (1);
(3) test the efficacy of anticipated policies in attaining the pursued policy objectives;
(4) when required, formulate alternative policy scenarios that better effectuate the pursued objectives.

Modelling enables a transparent and consistent quantification of differences between specialised and mixed farming systems and allows *ex ante* assessment of the impact of changes in policy environment on these farming systems. The multiple goal linear programming (MGLP) model developed in this study

optimises the configuration of regionally specialised or mixed farming systems, subject to a set of constraints, to one of a set of defined objectives, selecting from a large set of agricultural activities.

Chapter 2 was written before developing the MGLP model. One of its purposes was to identify the major issues that play a role when analysing specialised and mixed farming systems, and so to guide the conceptual design of the model. Chapter 2 quantifies the environmental and economic effects of merging a specialised arable farm and a specialised dairy farm to one mixed farming system. The results show that labour income per ha in the mixed farming system was 25% higher than the sum of labour incomes in both specialised farms. Seventy percent of this increase could be explained through higher yields per ha of the profitable crops ware potato and sugar beet. The remaining 30% resulted from lower costs, mainly through better utilisation of available labour. Differences between the combined nutrient balance of both specialised farms and that of the mixed farming system were small. Indications of reduced pesticide use in the mixed farming system could not be found. It was concluded that in a mixed farming system a higher labour income can be realised without increasing environmental pollution. Key factor is the ratio between animal and arable production, determining the extent to which crop rotations can be widened and the relative amounts of slurry that can be applied to grassland.

In *Chapter 3*, agricultural activities eligible for adoption in farming systems are defined, as part of the modelling framework. In addition, part of the input-output coefficients of each activity are quantified, notably agronomic coefficients. Defined agricultural activities refer to arable cropping, dairy farming and landless pig production. Arable crop production activities are characterised by six definition criteria, including crop species, cropping frequency and nitrogen application rate. The main definition criteria of milk production activities are nitrogen application rate, stocking rate, grazing system and milk production level. The characterisation of pig production activities covers two housing systems and two feeding systems.

The MGLP model is described in *Chapter 4*. The model is formulated as an optimisation matrix, consisting of rows and columns. The rows in this matrix are linear mathematical equations representing objective functions and restrictions. The columns are the decision variables in these equations, representing crop production activities, milk production activities and pig production activities. Two types of organisation of farming systems are distinguished: specialised farming and mixed farming. In addition to describing

the governing principles underlying the definition of decision variables, restrictions and objective functions, additional required input-output coefficients are quantified.

In *Chapter 5*, the MGLP model is applied to investigate the 'behaviour' of specialised and mixed farming systems subject to Dutch manure policy regulations foreseen for the year 2003. Simultaneously, the efficacy of manure policy regulations in reducing excess nitrate (NO_3-N) and ammonia (NH_3-N) emissions is evaluated. The configurations of specialised and mixed farming systems realising maximum labour income are explained, and the associated NO_3-N and NH_3-N emissions are confronted with policy standards. The results show that maximum labour income in the mixed farming system is much higher than in the specialised farming system. The difference is the result of a different impact of manure policy regulations on mixed farming systems, allowing higher production levels than in specialised farming systems. Despite compliance with manure policy regulations, N-emissions exceed the NO_3-N and NH_3-N policy standards, both in specialised and mixed farming systems. Configurations of farming systems complying with the policy standards are characterised by reduced N-inputs and reduced animal densities, resulting in considerable reductions in labour income.

In *Chapter 6*, the MGLP model is applied to assess the efficacy of adjustments to the design of manure policy regulations in reducing excess NO_3-N emission. The chapter focuses on the main Dutch policy instrument to restrict NO_3-N emissions from farms: the MINeral Accounting System (MINAS). MINAS is based on farm gate nitrogen (N) and phosphorus (P) balances in which nutrient surplus is calculated as total inputs minus total outputs. If the surplus exceeds a policy-defined levy-free threshold, the farmer has to pay a levy proportional to the excess. The levy-free N surplus is differentiated according to land use, distinguishing between grassland and arable land. Based on the properties of the specialised and mixed farming systems in Chapter 5, promising adjustments to the MINAS system are implemented in the MGLP model and effects on NO_3-N-loss and labour income quantified. The optimisations show that a gap exists between current policy-defined levy-free N surpluses and levy-free N surpluses required to attain the policy standard for NO_3-N leaching. This gap is larger as arable cropping is more important in terms of area use. Reducing the current levy-free surpluses to the required values has limited effects on labour income in all farming systems. It is concluded that if MINAS is to substantially reduce NO_3-N loss from agriculture, levy-free N surpluses should be further differentiated, i.e. according to farming system, grazing system and the ratio of grassland and arable land. Such a differentiation is likely to severely complicate the feasibility and enforceability of the MINAS system. It is therefore argued that means-oriented regulations, targeted at reducing NO_3-N leaching, could be useful additional instruments in Dutch manure policy.

In *Chapter 7*, the MGLP model is applied to assess the impacts of two future CAP scenarios on optimal configuration of specialised and mixed farming systems. The first scenario represents the anticipated Agenda 2000 reform package. The second scenario is derived in response to the existing criticism on the CAP and implies elimination of all product-tied support (full liberalisation). Optimisations show that implementation of Agenda 2000 does not affect optimal design of farming systems, but reduces labour income in arable cropping and dairy farming and increases labour income from pig production. It is argued that Agenda 2000 is not likely to induce drastic changes in land use in the Netherlands other than resulting from autonomous developments. In contrast, full liberalisation has drastic consequences for labour income in arable cropping and dairy farming, and hence is likely associated with considerable changes in agricultural land use in the Netherlands. Farms will roughly be divided in two main categories: large-scale, highly specialised farms focussing on bulk production for world markets and farms combining food production with contributions to other goals of society.

Differences in environmental and economic performance between specialised and mixed farming systems, as quantified in this study, originated from agronomic-technical, organisational and institutional differences. Agronomic-technical differences derived from the integration of land use in the mixed farming system, resulting in lower cropping frequencies, higher mineralisation rates under arable crops and lower mineralisation rates under grassland. Lower cropping frequencies were assumed to result in lower incidence levels of soil-borne pests and diseases and for some crops, notably economically important ones, in higher yields per ha. Organisational differences resulted from the exchange of labour and machines in mixed farming systems, reducing the need to hire labour. Institutionally-based differences were related to differences in impacts of Dutch manure policy regulations on specialised and mixed farming systems, allowing higher production intensities in the latter.

Agronomic-technical differences between specialised and mixed farming systems do not result in systematic differences in environmental impact in terms of nutrient emissions per ha. Because mixed farming systems are less constrained by institutional manure policy regulations, they potentially have larger emissions. The body of evidence in literature supporting scope for reduced pesticide use in mixed farming systems - due to lower pest and disease incidence levels and to potentially reduced weed populations - was considered insufficient for firm conclusions.

A weakness of MINAS is that it still allows agricultural practices that are associated with relatively high leaching losses. Such practices identified in this study include autumn application of large quantities of animal manure to arable crops, including maize. Given that (1) the European Commission is not yet convinced of the efficacy of MINAS in sufficiently reducing leaching loss and (2) farmers undoubtedly oppose further reductions in levy-free N surpluses, it is argued that a wise strategy might be the implementation of additional policy instruments with two specifications: (a) specifically targeted to reducing leaching loss and (b) supported by farmers. These instruments should incorporate financial incentives discouraging autumn-application and promoting spring application of manure. Besides bringing closer the implementation of good agricultural practice, a policy promoting spring application may possibly meet more support from farmers, compared with reducing levy-free surpluses.

Samenvatting

Een toenemend besef van de onduurzaamheid van Nederlandse agrarische productiesystemen heeft, onder meer, geleid tot een hernieuwde belangstelling voor gemengde bedrijfssystemen. Achterliggende reden is de veronderstelling dat gemengde bedrijfssystemen ten opzichte van gespecialiseerde bedrijfssystemen enkele voordelen met zich meebrengen, zoals een betere benutting van nutriënten, een verminderd gebruik van externe inputs, een betere benutting van beschikbare arbeid en spreiding van inkomens-risico's. De belangrijkste mechanismen achter deze vermeende voordelen zijn het gebruik van regionaal geteelde krachtvoeders, een efficiënter gebruik van dierlijke mest en ruimere gewasrotaties. De aan gemengde bedrijfssystemen toegeschreven voordelen zijn echter niet eenduidig, bijvoorbeeld omdat ze óók in gespecialiseerde bedrijfssystemen gerealiseerd zouden kunnen worden. Daarom werd het in het kader van deze studie zinvol geacht de verschillen in economische en milieukundige 'performance' tussen gemengde en gespecialiseerde bedrijfssystemen op een systematische wijze te kwantificeren, met als doel een bijdrage te leveren aan de discussie over de wenselijkheid van het herintroduceren van gemengde bedrijfssystemen in Nederland. Geïnspireerd door in de nabije toekomst te verwachten belangrijke wijzigingen in de beleidsomgeving van de Nederlandse landbouw, is een tweede zwaartepunt van deze studie beleidsanalyse. Gerelateerd aan deze wijzigingen in de beleidsomgeving kunnen talrijke '*what if*' vragen opgeworpen worden. Dergelijke '*what if*' vragen die in deze studie aan de orde komen hebben betrekking op de optimale configuratie van gespecialiseerde en gemengde bedrijfssystemen onder het huidige Nederlandse mestbeleid, de effectiviteit van dit mestbeleid in het in voldoende mate reduceren van nutriënten-emissies vanuit de Nederlandse landbouw en de impact van beperkte en vergaande hervormingen van het zgn. Gemeenschappelijk Landbouwbeleid van de Europese Unie. De hoofdoelstellingen van deze studie zijn daarmee:

(1) systematisch kwantificeren van agronomisch-technische verschillen tussen gespecialiseerde en gemengde bedrijfssystemen;
(2) systematisch kwantificeren van verschillen in milieukundige en economische performance tussen gespecialiseerde en gemengde bedrijfssystemen, voortkomend uit agronomisch-technische verschillen gekwantificeerd onder (1), in voorgenomen en denkbare toekomstige beleidsomgevingen;
(3) toetsen van de effectiviteit van voorgenomen beleid in het bereiken van de doelstellingen van dat beleid;

(4) indien nodig, formuleren van beleidsopties die de kans op het bereiken van de nagestreefde doelstellingen verhogen.

Modellering biedt in principe de mogelijkheid om (1) verschillen tussen gespecialiseerde en gemengde bedrijfssystemen op een transparante en consistente wijze te kwantificeren en (2) de impact van veranderingen in de beleidsomgeving op die bedrijfssystemen *ex ante* te evalueren. In het kader van deze studie is een meervoudig doelprogrammerings-model (MDP) ontwikkeld. Dit model optimaliseert de configuratie van regionaal gespecialiseerde dan wel regionaal gemengde bedrijfssystemen, gegeven een aan deze bedrijfssystemen opgelegde set beperkingen en selecterend uit een groot aantal ter keuze staande 'landbouw-activiteiten', naar een door de gebruiker in te stellen doelstelling.
Voorafgaand aan het ontwikkelen van genoemd MDP-model werd *Hoofdstuk 2* geschreven. Eén van de doelen van dit hoofdstuk was het identificeren van de belangrijkste issues die een rol spelen bij het analyseren van gespecialiseerde en gemengde bedrijfssystemen, om zo bij te dragen aan het conceptuele ontwerp van het model. In hoofdstuk 2 worden de milieukundige en economische effecten gekwantificeerd van het samenvoegen van een gespecialiseerd akkerbouwbedrijf en een gespecialiseerd melkveebedrijf tot één gemengd bedrijf. De resultaten geven aan dat het arbeidsinkomen per hectare van het gemengde bedrijf 25% hoger is dan de gewogen som van de arbeidsinkomens per hectare in beide gespecialiseerde bedrijven. Zeventig procent van de toename in arbeidsinkomen in het gemengde bedrijf kon verklaard worden door hogere opbrengsten per hectare van de hoog-salderende gewassen consumptieaardappel en suikerbiet. De resterende 30% was het gevolg van lagere kosten in het gemengde bedrijf, ten gevolge van een betere benutting van beschikbare arbeid. De verschillen tussen de gecombineerde nutriëntenbalansen van beide gespecialiseerde bedrijven en die van het gemengde bedrijf waren klein. Indicaties dat in het gemengde bedrijf het gebruik van biociden kan worden teruggedrongen werden niet gevonden. Concluderend kan worden gesteld dat het in gemengde bedrijfssystemen mogelijk is een hoger arbeidsinkomen te behalen zonder dat dat gepaard gaat met een toename van de milieubelasting. Een belangrijke factor hierbij is de verhouding tussen het areaal grasland en voedergewassen en het areaal akkerbouwgewassen, omdat die verhouding bepalend is voor de

mate waarin gewasrotaties verruimd kunnen worden en voor de hoeveelheid dierlijke mest die aan grasland toegediend kan worden.

Hoofdstuk 3 beschrijft de eerste stap in de ontwikkeling van het MDP-modelinstrumentarium. Het betreft de definiëring van de ter keuze staande 'landbouw-activiteiten', die de bouwstenen vormen van gespecialiseerde dan wel gemengde bedrijfssystemen. Bovendien wordt een deel van de agronomische input-output coëfficiënten van elk van deze activiteiten gekwantificeerd. Landbouw-activiteiten die in deze studie in beschouwing zijn genomen hebben betrekking op grondgebonden akkerbouw en melkveehouderij en niet-grondgebonden vleesvarkenshouderij. Akkerbouw-activiteiten worden gekenmerkt door zes definitie-criteria, waaronder gewassoort, teeltfrequentie en stikstofgift. Belangrijkste definitie-criteria voor melkveehouderij-activiteiten betreffen stikstofgift, veedichtheid, beweidingssysteem en melkproductieniveau van de veestapel. Varkenshouderij-activiteiten worden gekarakteriseerd aan de hand van het huisvestingssysteem en het voedersysteem.

Het MDP-model wordt beschreven in *hoofdstuk 4*. Het model is geformuleerd als een optimaliserings-matrix, bestaande uit rijen en kolommen. De rijen in de matrix zijn de lineaire mathematische vergelijkingen die de doelstellingsfunctie(s) en beperkingen beschrijven. De kolommen zijn de beslissingsvariabelen van de mathematische vergelijkingen, voorstellende akkerbouw-, melkveehouderij- en vleesvarkenshouderij-activiteiten. In het model wordt onderscheid gemaakt in twee organisatie-vormen van de landbouw: gespecialiseerde landbouw en gemengde landbouw. Naast een beschrijving van de beginselen achter de definiëring van beslissingsvariabelen, beperkingen en doelstellingsfuncties, worden in hoofdstuk 4 aanvullende input-output coëfficiënten gekwantificeerd.

In *hoofdstuk 5* is het MDP-model toegepast om het 'gedrag' van gespecialiseerde en gemengde bedrijfssystemen te onderzoeken, onder geldigheid van de Nederlandse mestregelgeving voorzien voor het jaar 2003. Tegelijkertijd wordt de effectiviteit van de regelgeving getoetst in het terugdringen van de emissies van nitraat (NO_3) en ammoniak (NH_3) uit de landbouw. De ontwerpen van het gespecialiseerde bedrijfssysteem en het gemengde bedrijfssysteem met maximaal arbeidsinkomen worden toegelicht en de bijbehorende NO_3-N en NH_3-N emissies worden afgezet tegen beleidsdoelstellingen. De resultaten tonen aan dat het maximale arbeidsinkomen in het gemengde bedrijfssysteem veel hoger is dan in het gespecialiseerde bedrijfssysteem. Dat verschil in arbeidsinkomen wordt veroorzaakt door een geringere beperkende invloed van de mestregelgeving in het gemengde bedrijfssysteem, waardoor daarin een hoger productieniveau behaald kan worden. De Nederlandse mestregelgeving, voorzien voor 2003, laat NO_3-N en NH_3-N-emissies toe die de beleidsdoelstellingen overschrijden, zowel in gespecialiseerde als in gemengde bedrijfssystemen. Configuraties van bedrijfssystemen waarin N-emissies de doelstellingen *niet* overschrijden, worden gekenmerkt door lagere N-inputs en lagere veedichtheden en gaan gepaard met aanzienlijke reducties in arbeidsinkomen.

In *hoofdstuk 6* is het MDP model toegepast om aanpassingen in het mestbeleid te testen op hun effectiviteit in het terugdringen van NO_3-N-emissies, zodanig dat de beleidsdoelstellingen bereikt worden. De meeste aandacht gaat daarbij uit naar het belangrijkste instrument in de mestregelgeving ter reductie van NO_3-N emissies, te weten het MINeralen Aangifte Systeem (MINAS). MINAS is gebaseerd op een *farm gate* stikstof (N) en fosfor (P) balans, waarin het nutriëntenoverschot gedefinieerd wordt als het verschil tussen aanvoer en afvoer. Dit overschot gaat òf verloren naar het milieu, òf wordt tijdelijk vastgelegd in de bodem. Als het overschot een in het beleid vastgelegd heffingsvrij overschot (verder aangeduid als de 'verliesnorm') overschrijdt, moet de agrariër een heffing betalen over elke kg overschot boven de verliesnorm. In tegenstelling tot de verliesnorm voor P, is de verliesnorm voor N gedifferentieerd naar landgebruik, waarbij onderscheid wordt gemaakt tussen grasland en akkerland. Op basis van de eigenschappen van gespecialiseerde en gemengde bedrijfssystemen in hoofdstuk 5, worden perspectiefvolle aanpassingen van MINAS doorgevoerd in het MDP-model en de effecten op NO_3-N emissie en arbeidsinkomen gekwantificeerd. De uitgevoerde optimaliseringen laten zien dat er een kloof bestaat tussen de N-verliesnormen voorzien voor het jaar 2003 en de vereiste N-verliesnormen om de beleidsdoelstelling te realiseren. Deze kloof is groter naarmate op een groter deel van het areaal akkerbouw bedreven wordt. Het reduceren van de verliesnormen voorzien voor 2003 tot de vereiste waarden heeft in alle situaties een beperkt effect op het arbeidsinkomen. Concluderend wordt gesteld dat, indien de inzet van het beleidsinstrument MINAS is om de NO_3-N emissie uit de Nederlandse landbouw aanzienlijk te verlagen, N-verliesnormen verder gedifferentieerd zouden moeten worden naar bijvoorbeeld bedrijfssysteem, beweidingssysteem en de verhouding tussen grasland en akkerland. Het lijkt waarschijnlijk dat een dergelijke differentiatie de uitvoerbaarheid en handhaafbaarheid van het MINAS systeem in ernstige mate zou belemmeren. Daarom, zo wordt

beredeneerd, zouden middel-voorschriften, specifiek gericht op het verlagen van de NO_3-N emissie, zinvolle aanvullende instrumenten kunnen zijn in het Nederlandse mestbeleid.
In *hoofdstuk 7* worden de gevolgen van twee toekomst-scenarios voor het Gemeenschappelijk Landbouwbeleid (GLB) op de optimale configuratie van gespecialiseerde en gemengde bedrijfssystemen gekwantificeerd. Het eerste scenario is een reeds door regeringsleiders vastgestelde hervorming van het GLB in het kader van Agenda 2000, die geleidelijk geïmplementeerd zal worden in de periode 2000-2008. Het tweede scenario is opgesteld als antwoord op veelvuldig geuite kritiek op het GLB en behelst eliminering van alle product-gebonden financiële ondersteuning (volledige liberalisatie). De resultaten suggereren dat de in Agenda 2000 voorgestelde maatregelen geen effect hebben op het optimale ontwerp van bedrijfssystemen, maar wel leiden tot verlagingen van arbeidsinkomens in de akkerbouw- en melkveesector en tot een toename van het arbeidsinkomen in de vleesvarkenshouderij-sector. Er wordt beargumenteerd dat het niet waarschijnlijk is dat Agenda 2000 zal leiden tot ingrijpende veranderingen in het landgebruik in Nederland, anders dan geïnduceerd door autonome ontwikkelingen. Daarentegen gaat volledige liberalisatie gepaard met aanzienlijke teruggang in arbeidsinkomens in de akkerbouw- en melkveesector, en daarom waarschijnlijk ook met aanzienlijke veranderingen in landgebruik. In een scenario van volledige liberalisering, zullen landbouwbedrijven ruwweg in twee categorieën in te delen zijn: grootschalige, sterk gespecialiseerde bedrijven die zich richten op bulk-productie en bedrijven die voedselproductie combineren met bijdragen aan andere maatschappelijke doelen.

Verschillen in milieukundige en economische ‘performance’ tussen gespecialiseerde en gemengde bedrijfssystemen als gekwantificeerd in deze studie kunnen worden teruggevoerd tot agronomisch-technische verschillen, organisatorische verschillen en institutionele verschillen. Agronomisch-technische verschillen vinden hun oorsprong in de integratie van landgebruik in gemengde bedrijfssystemen, resulterend in lagere teeltfrequenties, hogere mineralisatie in akkerland en lagere mineralisatie in grasland. In deze studie is verondersteld dat lagere teeltfrequenties leiden tot een lagere bodem-gebonden ziekten- en plaagdruk en voor sommige gewassen, met name economisch interessante, tot hogere opbrengsten per ha. Organisatorische verschillen worden veroorzaakt door de uitruil van arbeid en machines in gemengde bedrijfssystemen, waardoor minder externe arbeid ingezet hoeft te worden. Institutionele verschillen vinden hun oorzaak in een verschil in impact van mestregelgeving op gespecialiseerde en gemengde bedrijfssystemen, in de laatste een hoger productieniveau toelatend.

Agronomisch-technische verschillen tussen gespecialiseerde en gemengde bedrijfsystemen resulteren niet in systematische verschillen in milieu-effecten in termen van nutriënten-emissies per ha. Omdat gemengde bedrijfssystemen in mindere mate beperkt worden door de mestregelgeving, leiden ze potentieel zelfs tot hogere emissies per ha. De aanwijzigingen in de literatuur dat het gebruik van biociden in gemengde bedrijfssystemen verder teruggedrongen kan worden dan in gespecialiseerde bedrijfssystemen - samenhangend met lagere ziekten- plaag- en onkruiddruk in eerstgenoemde - worden niet sterk genoeg geacht om er harde conclusies aan te kunnen verbinden.

Een zwak punt van MINAS is dat het nog steeds activiteiten toelaat die gepaard gaan met relatief hoge NO_3-N emissies. Een voorbeeld van zo'n activiteit vormt de aanwending van grote hoeveelheden dierlijke mest aan akkerbouwgewassen - waaronder maïs - in het najaar. Gegeven dat (1) de Europese Commissie nog niet overtuigd is van de doelmatigheid van MINAS in het in voldoende mate terugdringen van de NO_3-N emissie en (2) agrariërs ongetwijfeld te hoop zullen lopen tegen een verdere verlaging van verliesnormen, wordt beargumenteerd dat een aanbevelenswaardige strategie zou kunnen zijn om aanvullende beleidsinstrumenten te ontwikkelen en implementeren met twee specificaties: (a) specifiek gericht op het reduceren van uitspoelings-verliezen en (b) ondersteund door agrariërs. Dergelijke instrumenten zouden financiële prikkels moeten bevatten die najaarsaanwending van dierlijke mest op bouwland ontmoedigen en voorjaarsaanwending stimuleren. Behalve dat zo de implementatie van zgn. 'goede landbouwpraktijk' dichterbij wordt gebracht, zou een beleid dat voorjaarsaanwending stimuleert mogelijkerwijs ook kunnen rekenen op meer draagvlak onder agrariërs dan het verlagen van verliesnormen.

Appendices

Appendix 1.

N response experiments with arable crops and grass fitted to QUADMOD

Ware potato

Location	Name experimental farm	Years	Number of N response experiments
Nieuw Beerta	Feddemaheerd	1976-1977, 1978-1982	7
Wieringermeer	van Bemmelenhoeve	1975, 1978, 1979-1981	4
Lelystad	de Kandelaar	1976, 1979-1981	4
Lelystad	PAGV	1990	8
Colijnsplaat	Rusthoeve	1973, 1981	2
Westmaas	Westmaas	1974, 1976, 1978, 1981-1982	6
Marknesse	Lovinkhoeve	1977-1979, 1981-1983, 1985, 1987, 1989, 1990	18
Total:			49

Silage maize

Location	Name experimental farm	Years	Number of N response experiments
Lelystad	Waiboerhoeve	1976-1980	5
Lelystad	PAGV	1989, 1991-1992	3
Lelystad	PAGV	1991-1994	8
Total			16

Winter wheat

Location	Name experimental farm	Years	Number of N response experiments
Unknown	Unknown	1980-1987, 1989	21
Total			21

Sugar beet

Location	Name experimental farm	Years	Number of N response experiments
Flevoland	Unknown	1977-1979	12
Colijnsplaat	Rusthoeve	1987, 1990, 1991	3
Lelystad	de Kandelaar	1988, 1989	2
Wieringermeer	van Bemmelenhoeve	1988	1
Total			21

Fodder beet

Location	Name experimental farm	Years	Number of N response experiments
Merelbeke (B)	unknown	1995-1997	3
Tienen (B)	unknown	1995-1997	3
Hengelo	de Marke	1990	1
Heers (B)	unknown	unknown	1
Helecine (B)	unknown	1983, 1985	2
Tervuren	unknown	unknown	2
Total			12

Onion

Location	Name experimental farm	Years	Number of N response experiments
Bruinisse	-	1988	1
Zevenbergschehoek	-	1988	1
Ursem	-	1988	1
Biddinghuizen	-	1988	1
Marknesse	Lovinkhoeve	1988	1
Lelystad	PAGV	1991-1993	3
Wieringermeer	van Bemmelenhoeve	1992-1994	3
Colijnsplaat	Rusthoeve	1994	1
Total			12

White cabbage

Location	Name experimental farm	Years	Number of N response experiments
Wagenberg	-	1987	1
Breda	-	1987	1
Avenhorn	-	1987	1
Ursem	-	1987	1
Kloosterburen	-	1987	1
Bedum	-	1987	1
Haren	-	1987	1
Lelystad	PAGV	1992, 1993	4
Oudkarspel	-	1992, 1993	4
Warmenhuizen	-	1992, 1993	4
Total			19

Grass

Location	Name experimental farm	Years	Number of N response experiments
Dronten	A.P. Minderhoudhoeve	1984-1986	3
Lelystad	Waiboerhoeve	1990-1992	3
Southern Flevoland	unknown	1979-1982	4
Friens	unknown	1981-1983	3
Den Ham	opz.	1985-1986	2
Aduard	opz	1987-1988	2
Total			17

Appendix 2.
Yields, N fertiliser requirements, N uptakes and ANRs of crops cultivated in a disease free soil (e=1)[1].

Crop, cropping frequency, target yield	Values definition criteria r and n	Yield	N fertiliser requirement		N uptake	ANR
Maize in rotation, all cropping frequencies						
1.0*economically optimal yield	all r's, n=1	15302	142	(100)	174	0.57
0.95*economically optimal yield	all r's, n=2	14537	81	(57)	143	0.62
0.90*economically optimal yield	all r's, n=3	13772	61	(43)	131	0.62
Winter wheat, all cropping frequencies						
1.0*economically optimal yield	all r's, n=1	7950	206	(100)	240	0.62
0.95*economically optimal yield	all r's, n=2	7552	151	(73)	216	0.68
0.90*economically optimal yield	all r's, n=3	7155	120	(58)	196	0.69
White cabbage, all cropping frequencies						
1.0*economically optimal yield	all r's, n=1	99851	376	(100)	357	0.60
0.95*economically optimal yield	all r's, n=2	94858	249	(66)	307	0.70
0.90*economically optimal yield	all r's, n=3	89866	218	(58)	286	0.71
Onion, all cropping frequencies						
1.0*economically optimal yield	all r's, n=1	64951	124	(100)	145	0.42
0.95*economically optimal yield	all r's, n=2	61703	54	(44)	119	0.50
0.90*economically optimal yield	all r's, n=3	58455	37	(30)	110	0.50
Sugar beet, 1:2						
1.0*economically optimal yield	r=1, n=1	47838	0	-	164	-
0.95*economically optimal yield	r=1, n=2	n.a.	n.a.	n.a.	n.a.	n.a.
0.90*economically optimal yield	r=1, n=3	n.a.	n.a.	n.a.	n.a.	n.a.
Sugar beet, 1:4						
1.0*economically optimal yield	r=3, n=1	65679	126	(100)	244	0.63
0.95*economically optimal yield	r=3, n=2	62393	19	(15)	178	0.75
0.90*economically optimal yield	r=3, n=3	60766	0	(0)	164	-
Sugar beet, 1:6						
1.0*economically optimal yield	r=5, n=1	70157	153	(100)	260	0.62
0.95*economically optimal yield	r=5, n=2	66647	39	(25)	195	0.77
0.90*economically optimal yield	r=5, n=3	63139	7	(4)	170	0.77

[1] *Maize: aboveground dm yield, aboveground N uptake; Winter wheat: dm yield grains, aboveground N uptake. N uptake in winter wheat straw was calculated assuming a nitrogen harvest index (NHI) of 0.77 (Anonymous, 1997b; Darwinkel, 1998); Onion: fresh yield bulbs, N uptake bulbs and foliage; Sugar beet: fresh beet yield adjusted to a sugar content of 16%, whole crop N uptake. N uptake in sugar beet leaves was estimated assuming a NHI of 0.42 for N rates >80 and of 0.46 for unfertilised objects (van der Beek & Wilting, 1994). NHI's for intermediate N rates were estimated by interpolation; White cabbage: fresh marketable yield, aboveground N uptake.*

Appendix 2 (continued).
Yields, N fertiliser requirements, N uptakes and ANRs of crops cultivated in a disease free soil (e=1)[1].

Crop, cropping frequency, target yield	Values definition criteria r and n	Yield	N fertiliser requirement		N uptake	ANR
Fodder beet, 1:2						
1.0*economically optimal yield	r=1, n=1	11200	39	(100)	187	0.56
0.95*economically optimal yield	r=1, n=2	10995	0	(0)	165	-
0.90*economically optimal yield	r=1, n=3	n.a.	n.a.	n.a.	n.a.	n.a.
Fodder beet, 1:4						
1.0*economically optimal yield	r=3, n=1	15399	145	(100)	258	0.64
0.95*economically optimal yield	r=3, n=2	14628	54	(37)	203	0.69
0.90*economically optimal yield	r=3, n=3	13857	33	(23)	189	0.69
Fodder beet, 1:6						
1.0*economically optimal yield	r=5, n=1	16449	171	(100)	275	0.64
0.95*economically optimal yield	r=5, n=2	15626	74	(43)	217	0.69
0.90*economically optimal yield	r=5, n=3	14802	52	(30)	201	0.69
Green pea						
Cropping frequency 1:2	r=1	3685	-	-	142	-
Cropping frequency 1:4	r=3	4422	-	-	171	-
Cropping frequency 1:6	r=5	4668	-	-	180	-

[1] *Fodder beet: beet dm yield, whole crop N uptake. N uptake in fodder beet leaves was estimated assuming a NHI of 0.55 for all N rates; Green pea: grain dm yield, N uptake in grains.*

Appendix 3.

Monthly mineralisation rate

Monthly mineralisation rate (in kg N ha^{-1}) as related to monthly temperatures (Rijtema, in Lammers, 1983; Schröder, 2002), assuming annual mineralisation of 120 kg N ha^{-1} yr^{-1} (Bloem *et al.*, 1994; Vos & Heinen, 1999)

month	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
temperature	1.7	2.0	5.0	8.5	12.4	15.5	17.0	16.8	14.3	10.0	5.9	3.0
mineralisation	3.7	3.3	5.2	7.1	11.8	16.4	19.9	19.2	14.3	8.9	5.7	4.4

Derivation of crop-specific parameters

Maize in rotation

In the N response experiments with maize, measurements of N uptake referred to aboveground N uptake. It is assumed that roots and stover contain 21 kg N, irrespective of N rate (Schröder, 1998; van de Ven, 1996). Hence, $N_{cropres}$ is 21 kg N. Harvest date of maize is set to 1 October, implying that M_{nets} and M_{neta} equal 94 and 9 kg N, respectively. Van der Schans *et al.* (1995), Schröder (1985) and van Dijk (1996) measured residual soil mineral N levels in the upper 60 cm after harvest of maize cultivated at clay soils. For the purpose of this study, these values have been standardised to values for the upper 100 cm using the equation residual $N_{0\text{-}100cm}$ = (residual $N_{0\text{-}60cm}$*1.12) + 13 (Schröder *et al.*, 1996). Standardised observations are shown in Figure A3.1. N_{res} values applied in this study were eye-fitted and set to 60, 38 and 31 kg N ha^{-1} for maize given 142, 81 and 61 kg N, respectively.

Maize can either be harvested for silage making or as CCM. CCM yield comprises 50% of the dm yield of maize for silage making (Anonymous, 1993a). NHI of CCM, relative to maize for silage making, is 0.60 (van de Ven, 1996).

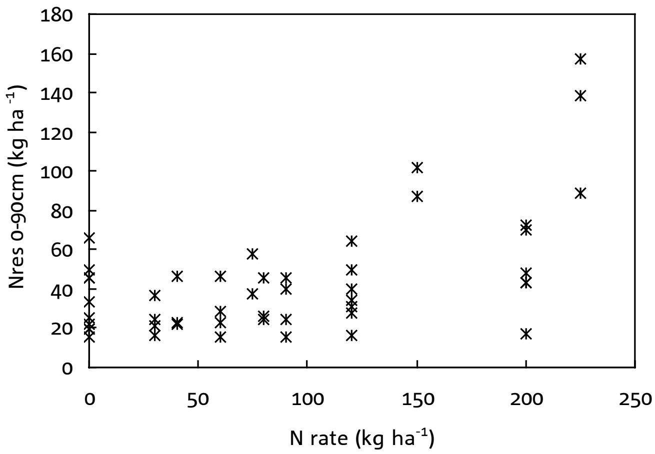

Figure A3.1. *$NRES_{0-100}$ values after harvest of maize (van der Schans* et al.*, 1995; Schröder, 1985; van Dijk, 1996).*

Onion

In the N response experiments with onion, measurements of N uptake referred to uptake in bulbs and foliage. N amounts in these crop parts were measured separately. Measurements showed that on average 79, 76 and 73% of total N was in bulbs of crops given 0-100, 100-200 and >200 kg N ha^{-1}, respectively. These percentages were used to partition N uptake in bulbs and foliage over N uptake in bulbs and N uptake in foliage for the three yield levels defined. It is assumed that 20% of total N taken up by an onion crop is incorporated in roots (after Greenwood *et al.*, 1992). $N_{cropres}$ is the amount of N contained in roots and foliage, amounting to 71, 55 and 51 kg N for n=1, n=2 and n=3, respectively. Harvest date of onion is set to 1 September, implying that M_{nets} and M_{neta} equal 80 and 23 kg N, respectively. In five trials with onion conducted in the Netherlands in 1988, Greenwood *et al.* (1992) found that applying 150 kg N ha^{-1} increased residual soil mineral N levels in the upper 100 cm after harvest to 82 kg N ha^{-1} from 50 when no fertiliser was applied. N_{res} values applied in this study have been determined by interpolation between these extremes and amount to 74, 51 and 50 kg N for onion fertilised with 124, 54 and 37 kg N, respectively.

White cabbage

In the N response experiments with white cabbage, measurements of N uptake referred to uptake in the whole plant excluding the roots. White cabbage has a well-developed root system, but data on N incorporated in roots are lacking. Here it is assumed that roots contain 10% of total N taken up by white cabbage. NHI is set to 0.50 (Everaarts, 1993; Slangen *et al.*, 1990). $N_{cropres}$ is the amount of N contained in stubble and roots, amounting to 198, 171 and 159 kg N for n=1, n=2 and n=3, respectively. Harvest date of white cabbage is set to 1 November, implying that M_{nets} and M_{neta} amount to 103 and 0 kg N, respectively. Residual soil mineral N levels as observed in 13 trials in five different years are shown in Figure A3.2 (Neeteson & Wadman, 1991; Everaarts & De Moel, 1995). Based on these sources N_{res} is set to 60, 40 and 30 kg N, after cabbage crops given 376, 249 and 218 kg N.

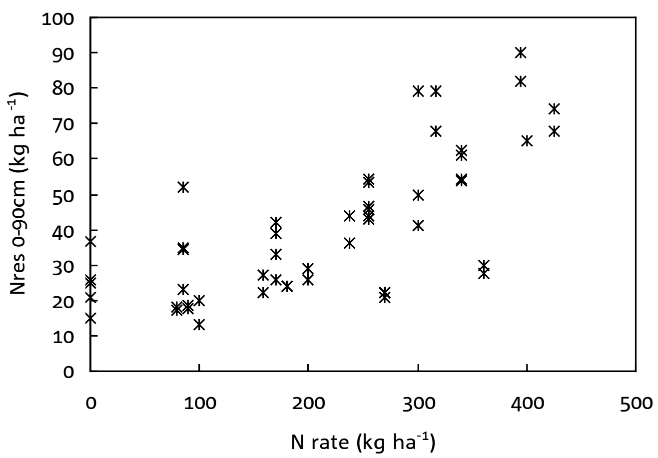

Figure A3.2. $NRES_{0-90}$ values after harvest of white cabbage (Neeteson & Wadman, 1991; Everaarts & De Moel, 1995).

Winter wheat

In the N response experiments with winter wheat, measurements of N uptake referred to uptake in grains. N uptake in winter wheat straw is calculated using a NHI of 0.77 (Anonymous, 1997b; Darwinkel, 1998). The amount of N contained in roots and straw is set to 30 kg N ha^{-1} (Prins *et al.*, 1988). $N_{cropres}$ depends on the fate of straw (harvested/left in the field). If straw is harvested, $N_{cropres}$ amounts to 30 kg N ha^{-1} for all n-levels. If straw is left in the field, $N_{cropres}$ amounts to 85, 80 and 75 kg N ha^{-1} for n=1, n=2 and n=3, respectively. Harvest date of winter wheat is set to 15 August, implying that M_{nets} and M_{neta} amount to 70 and 33 kg N, respectively. Residual soil mineral N levels as observed in 20 trials on clay soils increased from 17 (0N) to 33 kg N (220 kg N) (van Enckevort *et al.*, 2002). N_{res} values applied in this study have been determined by interpolation between these extremes and amount to 32, 28 and 26 kg N for winter wheat fertilised with 206, 151 and 120 kg N, respectively.

Sugar beet

In the N response experiments with sugar beet, neither N uptake in beets nor in leaves was directly measured. N uptake in beets (in mmol kg^{-1} fresh beet) was calculated from their measured α-amino-N contents (in mmol kg^{-1} fresh beet), using the equation y=2.22x + 66 (R^2 = 0.74) (pers. comm. T. Huijbregts, IRS) and subsequently converted to N uptake in beets in kg N ha^{-1}. N uptake in beet leaves was estimated assuming a NHI of 0.46 for unfertilised crops and of 0.42 for sugar beet crops given more than 80 kg N. These NHI's were derived from 10 trials in three different years (van der Beek & Wilting, 1994). $N_{cropres}$ is the amount of N contained in leaves. NHI's for N application rates used in this study were determined by interpolation between the extremes 0.46 (0N) and 0.42 (80 kg N or more). Harvest date of sugar beets is set to 1 November, hence M_{nets} and M_{neta} amount to 103 and 0 kg N, respectively. Residual soil mineral N levels, measured after cultivation of sugar beet are shown in Figure A3.3 (Schröder *et al.*, 1996; Allison *et al.*, 1996; Neeteson & Ehlert, 1989; Webb *et al.*, 2000). Residual soil mineral N hardly increases with increasing fertiliser rates. Even sugar beets given extremely high N rates, generally show values less than 40 kg N ha^{-1} (Neeteson & Wadman, 1991). It is therefore assumed that N_{res} values following sugar beet given 0, 100, 150, 200 and 250 kg N are 20, 30, 40, 40 and 40 kg N respectively. Values applicable in this study are determined by interpolation.

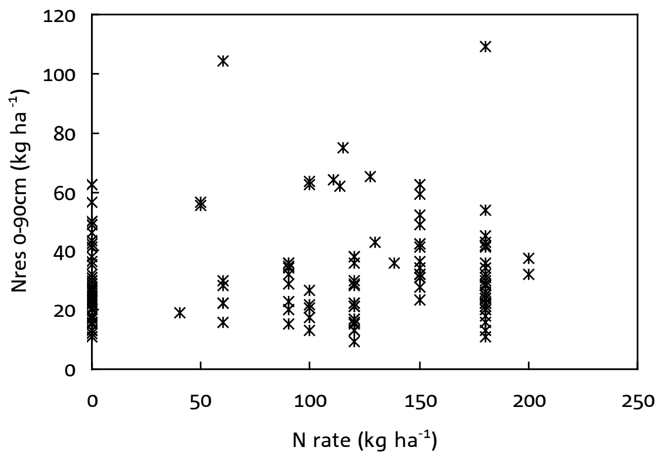

Figure A3.3. *$NRES_{0\text{-}90}$ after harvest of sugar beet (Schröder* et al.*, 1996; Allison* et al.*, 1996; Neeteson & Ehlert, 1989).*

Fodder beet

In the N response experiments with fodder beet, N uptake was measured both in beets and in leaves. The experiments did not show a decreasing NHI with increasing N application rate. Average NHI amounted to 0.55. This value has been used for all n-levels. $N_{cropres}$ is the amount of N contained in leaves. Harvest date of sugar beets is set to 15 October, hence M_{nets} and M_{neta} amount to 98 and 4 kg N, respectively. N_{res} values for sugar beet are also assumed to be valid for fodder beet.

Pea

N uptake in grains of green pea was calculated as the product of grain yield and N content. N content of grain dm was fixed at 3.9% (average of 4 years; Jensen 1986; 1987). Of total N in the crop at maturity, 69% is assumed to be in the grains, 22% in aboveground crop residues and 9% in roots (Jensen, 1997). N_{fix} is set to 73% of total N uptake (average of 4 years; Jensen 1986; 1987). Harvest date of green pea is set to 1 September, hence M_{nets} and M_{neta} amount to 80 and 23 kg N, respectively. Residual N immediately after harvest at maturity stage is set to 80 kg N ha^{-1} for pea cultivated without yield reductions

(Jensen, 1989; Jensen & Haahr, 1989). In the first 3 months after harvest 40% of N in roots (Jensen, 1996) and 25% of N in aboveground crop residues (Jensen, 1997) is mineralised, increasing residual N after green pea. Hence, N_{res} after green pea without yield reductions is set to 80 kg N ha^{-1} increased by the amount mineralising from above- and belowground crop residues in the initial 3 months after harvest. $N_{cropres}$ is calculated as the amount of N in roots and pea straw at harvest minus N mineralised from these sources in the first three months after harvest. N_{res} values applicable to pea production activities with yield reductions (`e`=2 and/or `r`<6), are calculated from the N_{res} value without yield reduction, with the soil surface balance in autumn ($N_{atms}+M_{nets}+M_{neta}+N_{fix}-N_{prod}-N_{cropres}$) serving as an indicator.

Appendix 4.

P contents arable crops

Crop	P content	unit	source
Onions	2970	g P per ton fresh bulbs	Anon., 1993b
Maize	2000	g P per ton dm	Anon., 1999b
White cabbage	320	g P per ton fresh	Everaarts & de Moel, 1995
Sugar beet: beets	437	g P per ton fresh beets	Anon., 1994
Sugar beet: leaves	400	g P per ton fresh leaves	Anon., 1999b
Fodder beet: beets	1800	g P per ton dm beets	Anon., 1999b
Fodder beet: leaves	2300	g P per ton dm leaves	Anon., 1999b
Winter wheat: grains	3700	g P per ton dm grains	Anon., 1999b
Winter wheat: straw	1000	g P per ton dm straw	Anon., 1997b
Ware potato	2259	g P per ton dm tubers	Stouthart & Leferink, 1992
Peas	5046	g P per ton dm dry peas	Anon., 1999b

Appendix 5.

List of indices used in the MGLP model

Index	Definition	Variants
`aa`	method to apply cattle and pig slurry	1. injection
		2. sod-fertilisation (only in grassland)
`bb`	grassland utilisation method	1. zero grazing, no supply of maize silage
		2. zero grazing, supply of maize silage
		3. day-and-night grazing, no supply of maize silage
		4. day grazing, supply of maize silage
`cc`	herbage supply level	1. maximum herbage intake
		2. 0.9 times maximum herbage intake
		3. 0.8 times maximum herbage intake
`d`	amount of slurry applied	1. application of slurry not exceeding N uptake capacity of catch crop
		2. application of slurry exceeding N uptake capacity of catch crop
`e`	soil disease status due to previous crop	1. no damage
		2. damage level 1
		3. damage level 2
		4. etc.
`F`	feeding system for pigs	1. standard compound feeds and/or CCM
		2. crushed wheat combined with supplementary compound feeds
`ff`	conserved product of grassland fed in winter	1. hay (cut at 4000 kg dm ha^{-1})
		2. grass silage (cut at 4000 kg dm^{-1})
		3. grass silage (cut at 3000 kg dm^{-1})
		4. artificially dried grass (cut at 3000 kg dm^{-1})
`gg`	grassland category/ arable crop species	1. grazed grassland
		2. cut grassland
		3. 1st year grassland
and	and	4. 2nd year grassland
		5. 3rd year grassland
`z`	preceding crop	6. 4th year grassland
		7. maize
		8. ware potato
		9. sugar beet
		10. onion
		11. winter wheat
		12. peas
		13. white cabbage

Appendix 5. (continued)

List of indices used in the MGLP model

Index	Definition	Variants
h	farming system	1. specialised farming: rotation of arable crops, occupying 100% of the available area 2. specialised farming: permanent grassland and/or continuous maize; arable crops in separate rotation, occupying 20% of the available area 3. specialised farming: permanent grassland and/or continuous maize; arable crops in separate rotation, occupying 33% of the available area 4. specialised farming: permanent grassland and/or continuous maize; arable crops in separate rotation, occupying 43% of the available area 5. specialised farming: permanent grassland and/or continuous maize; arable crops in separate rotation, occupying 50% of the available area 6. specialised farming: permanent grassland and/or continuous maize; arable crops in separate rotation, occupying 56% of the available area 7. specialised farming: permanent grassland and/or continuous maize; arable crops in separate rotation, occupying 60% of the available area 8. specialised farming: permanent grassland and/or continuous maize, occupying 100% of the available area 9. mixed farming: grassland and/or maize in rotation with arable crops with one arable crop between 4th year grassland and 1st year grassland 10. mixed farming: grassland and/or maize in rotation with arable crops with two arable crops between 4th year grassland and 1st year grassland 11. mixed farming: grassland and/or maize in rotation with arable crops with three arable crops between 4th year grassland and 1st year grassland 12. mixed farming: grassland and/or maize in rotation with arable crops with four arable crops between 4th year grassland and 1st year grassland 13. mixed farming: grassland and/or maize in rotation with arable crops with five arable crops between 4th year grassland and 1st year grassland 14. mixed farming: grassland and/or maize in rotation with arable crops with six arable crops between 4th year grassland and 1st year grassland
mm	milk production level	1. no milk (young stock) 2. 5000 kg milk per cow per year 3. 6500 kg milk per cow per year 4. 8000 kg milk per cow per year
n	N application level for arable crops	1. N application to reach 100% of economically optimal yield 2. N application to reach 95% of economically optimal yield 3. N application to reach 90% of economically optimal yield
nn	N application level for grassland	1. N application rate grassland 50 2. N application rate grassland 100 3. N application rate grassland 150 4. N application rate grassland 200 5. N application rate grassland 250 6. N application rate grassland 300 7. N application rate grassland 350 8. N application rate grassland 400

Appendix 5. (continued)
List of indices used in the MGLP model

Index	Definition	Variants			
p	direct area payment	1.	not opting for direct area payment		
		2.	opting for direct area payment; 10% of the area under set-aside		
pp	period in a year in dairy farming	1.	summer period		
		2.	winter period		
q	two week period in a year	1.	1st and 2nd week of the calendar year		
		2.	3rd and 4th week of the calendar year		
		3.	etc.		
		26.	51st and 52nd week of the calendar year		
qq	harvested product of crops	1.	maize harvested for silage making, beet harvested as sugar beet (excluding leaves), winter wheat harvested for bread-making (excluding straw)		
		2.	maize harvested as CCM, beet harvested as fodder beet (excluding leaves), winter wheat harvested as feed grain (including straw)		
r	cropping frequency	1.	1:2	6.	1:7
		2.	1:3	7.	1:8
		3.	1:4	8.	1:9
		4.	1:5	9.	1:10
		5.	1:6		
T	compound feed type for pigs	1.	standard 'starter' feed		
		2.	standard 'grower' feed		
		3.	standard 'finisher' feed		
		4.	protein-rich 'starter' feed, fitting in rations with grains		
		5.	protein-rich 'grower and finisher' feed, fitting in rations with grains		
tt	concentrate type for cattle	1.	low protein concentrate	4.	protein-rich concentrate
		2.	standard concentrate	5.	very protein-rich concentrate
		3.	moderately protein-rich concentrate	6.	low phosphorus concentrate
S	housing system for pigs	1.	conventional housing system		
		2.	free range system		
ss	slurry type	1.	cattle slurry		
		2.	pig slurry		
U	phase in the pig fattening period	1.	phase 1: 26 – 40 kg		
		2.	phase 2: 41 – 70 kg		
		3.	phase 3: 71 – 113 kg		

Appendix 5. (continued)

List of indices used in the MGLP model

Index	Definition	Variants
y	feasible combination of cropping frequencies in one rotation	1. combination of cropping frequencies 1:2 and/or 1:4 and/or 1:8 2. combination of cropping frequencies 1:2 and/or 1:6 3. combination of cropping frequencies 1:3 and/or 1:6 4. combination of cropping frequencies 1:3 and/or 1:9 5. combination of cropping frequencies 1:5 and/or 1:10 6. all crops with cropping frequency 1:7
yy	cattle type	1. dairy cows 2. calves 3. yearlings
zz	cattle stable and slurry storage type	1. current stable and slurry storage type 2. slurry storage covered, stable adapted to low ammonia emissions (Green Label)

Appendix 6.

List of decision variables defined in the MGLP model

Land use variables

`BINCR(h,gg,r,y):`	Binary variable to assign the appropriate area to crop gg with cropping frequency r in cropping frequency combination y in farming system h [0/1]
`BINRO(y):`	Binary variable to select only one cropping frequency combination y in a rotation [0/1]
`BINPR(h,gg,z,r):`	Binary variable to assign the appropriate area to crop gg preceded by crop z with cropping frequency r in farming system h [0/1]
`XAREA(h):`	Binary variable representing the total area available for land use variables in farming system h [0/1]
`XC(h,gg,e,r,p,n,qq):`	Area of crop gg in farming system h with cropping frequency r, direct area payment p, N application level n in a soil with disease status e and harvested as crop product qq [ha]
`XF(h,f,nn):`	Area of grass for conservation in farming system h at N application level nn [ha]
`XG(yy,bb,nn,cc,mm,h):`	Area of grass for grazing in farming system h with grassland utilisation method bb and N application level nn, grazed by cattle type yy with milk production level mm at herbage supply level cc [ha]
`XM(h,e,p,n,qq):`	Area of continuously cropped maize in farming system h, direct area payment p, N application level n in a soil with disease status e and harvested as maize product qq [ha]
`XPR(h,gg,e,z,r):`	Area of crop gg in a soil with disease status e preceded by crop z with frequency r in farming system h [ha]

Cattle feeding variables

`XCN(tt,pp,yy,mm,zz):`	Purchased concentrate intake of type tt in period pp by cattle type yy with milk production level mm in stable and storage type zz [kg]
`XCONC(yy,mm,zz):`	Purchased and internally produced concentrate intake in winter by cattle type yy with milk production level mm in stable and storage type zz [kg]
`XDMIW(yy,mm,zz):`	Dry matter intake in winter by cattle type yy with milk production level mm in stable and storage type zz [kg]
`XFV(ff,nn,yy,mm,zz):`	Feeding of conserved grass product ff cultivated at N application nn to cattle type yy with milk production level mm in stable and storage type zz [kg]
`XS(h,pp,yy,mm,zz,n):`	Feeding of maize silage cultivated in farming system h at N application level n to cattle type yy with milk production level mm in stable and storage type zz in period pp [kg]
`XT(h,pp,yy,mm,zz,n):`	Feeding of CCM cultivated in farming system h at N application level n to cattle type yy with milk production level mm in stable and storage type zz in period pp [kg]
`XVBB(e,yy,mm,zz,n):`	Feeding of fodder beet cultivated in a soil with disease status e at N application level n to cattle type yy with milk production level mm in stable and storage type zz [kg]
`XVWG(e,pp,yy,mm,zz,n):`	Feeding of winter wheat grains cultivated in a soil with disease status e at N application level n in period pp to cattle type yy with milk production level mm in stable and storage type zz [kg]
`XVGPS(e,pp,yy,mm,zz,n):`	Feeding of whole crop cereal silage cultivated in a soil with disease status e at N application level n in period pp to cattle type yy with milk production level mm in stable and storage type zz [kg]

Appendix 6. (continued)

List of decision variables defined in the MGLP model

Pig feeding variables

XDMPI(S,F,U,zz):	Feed intake by pigs in housing system S in phase U and feeding system F in stable and storage type zz [kg]
XPC(S,F,U,T,zz):	Feeding compound feed type T to pigs in housing system S, feeding system F and phase U in stable and storage type zz [kg]
XWGV(e,S,F,U,n,zz):	Feeding crushed wheat grains cultivated in a soil with disease status e at N application level n to pigs in housing system S, feeding system F and phase U in stable and storage type zz [kg]
XCCMV(h,S,F,U,n,zz):	Feeding CCM cultivated in farming system h at N application n to pigs in housing system S, feeding system F and phase U in stable and storage type zz [kg]

Fertilising variables

BINSL(h,gg,ss,d,z):	Binary variable to select amount d of slurry type ss applied to crop gg preceded by crop z cultivated in farming system h [0/1]
XCSG(h,aa,gg):	Cattle slurry application to grassland type gg using method aa in farming system h [kg N]
XCS1(h,aa,gg):	Cattle slurry application below N uptake capacity of catch crop to arable crop gg using method aa in farming system h [kg N]
XCS2(h,aa,gg):	Cattle slurry application above N uptake capacity of catch crop to arable crop gg using method aa in farming system h [kg N]
XCS(h,aa,gg):	Cattle slurry application without catch crop to arable crop gg using method aa in farming system h [kg N]
XNFEC(h,gg):	Mineral N fertiliser application to arable crop gg in farming system h [kg N]
XNFEG(h,gg):	Mineral N fertiliser application to grassland gg in farming system h [kg N]
XNFEM(h):	Mineral N fertiliser application to continuously cropped maize in farming system h [kg N]
XNFERT:	Mineral N fertiliser application to arable crops corrected for accumulation of mineral N [kg N]
XPFER(gg):	Mineral P fertiliser application in crop gg [kg P]
XPSG(h,aa,gg):	Pig slurry application to grassland type gg using method aa in farming system h [kg N]
XPS1(h,aa,gg):	Pig slurry application below N uptake capacity of catch crop to arable crop gg using method aa in farming system h [kg N]
XPS2(h,aa,gg):	Pig slurry application above N uptake capacity of catch crop to arable crop gg using method aa in farming system h [kg N]
XPS(h,aa,gg):	Pig slurry application without catch crop to arable crop gg using method aa in farming system h [kg N]
XPMAN(h,gg):	Application of solid pig manure to arable crop gg in farming system h [kg N]

Internal N and P flows

XCFLN:	N in conservation and feeding losses in dairy farming [kg]
XNSL(yy,mm,pp,zz):	N excretion in slurry by cattle type yy with milk production level mm in stable and storage type zz in period pp [kg]
XNACS:	N in cattle slurry at the moment of application [kg]
XPFLN:	N in feeding losses in pig production [kg]

Appendix 6. (continued)

List of decision variables defined in the MGLP model

XNEXP(S,F,zz):	N excretion in slurry by pigs in housing system S and feeding system F in stable and storage type zz [kg]
XNAPS:	N in pig slurry at the moment of application [kg]
XNAPMAN:	N in solid pig manure at the moment of application [kg]
XNBLC(h):	Organic N balance of the arable crop rotation in farming system h [kg]
XNBLF(h):	Organic N balance of cut grassland in farming system h [kg]
XNBLG(h):	Organic N balance of grazed grassland in farming system h [kg]
XNBLM(h):	Organic N balance of continuously cropped maize in farming system h [kg]
XNBLROT(h):	Organic N balance of mixed rotations in farming system h [kg]
XNSUM:	N counter [kg]
XSTRAWINT(h,e,n):	Straw cultivated in a soil with disease status e at N application level n for use in free range pig farming systems in farming system h [kg]
N and P losses	
XACLN:	N in arable crops lost during storage [kg]
XNO3T:	Total NO_3-N leaching loss [kg]
XNOV:	Agronomic N surplus [kg]
XNDENI	Total denitrification loss [kg]
XN2OT:	Total N_2O-N loss [kg]
XNH3P(S,F,zz):	NH_3-N volatilisation from stable and storage type zz and pig housing system S with pigs in feeding system F [kg]
XNH3S(yy,zz,pp):	NH_3-N volatilisation from stable and storage type zz in period pp from slurry produced by cattle type yy [kg]
XNH3T:	Total NH_3-N volatilisation [kg]
XPOV:	Agronomic P surplus [kg]
Purchase variables	
XCCLT:	Total contract labour costs [€]
XCCLA:	Contract labour costs in the arable sector [€]
XCCLM:	Contract labour costs in the dairy sector [€]
XCT(tt,pp):	Gross amount of concentrates of type tt purchased for feeding to cattle in period pp [kg]
XPTOT(T):	Gross amount of compound feeds of type T purchased [kg]
XFIXA:	Fixed costs of the arable sector [€]
XFIXM:	Fixed costs of the dairy sector [€]
XFIXP:	Fixed costs of the pig sector [€]
XFIXT:	Total fixed costs [€]
XPUR(yy,bb,nn,cc,mm)	Purchase of cattle type yy with milk production level mm, kept under grassland utilisation method bb with N application level nn, at herbage supply level cc [ha]
XVARA:	Variable costs in the arable sector [€]
XVARM:	Variable costs in the dairy sector [€]
XVARP:	Variable costs in the pig sector [€]
XVART	Total variable costs [€]
XSTRAWEXT:	Purchase of straw for use in free range pig farming systems [kg]

Appendix 6. (continued)

List of decision variables defined in the MGLP model

Sale variables

XMILK:	Total milk sold [kg]
XPISLL(S):	Number of pigs from housing system S sold at slaughter weight [head]
XSALC(gg,e,n,qq):	Sale of main product from crop gg at N application level n in a soil with disease status e and harvested as crop product qq to the external market [kg]
XSALY(yy):	Sale of surplus cattle type yy [head]
XSER(h,gg,e,n):	Sale of by-product from crop gg cultivated in a soil with disease status e at N application level n in farming system h [kg]

Miscellaneous variables

BINAMCOR(d):	Binary value that arranges that 'unavoidable' NH_3-N-loss is either negative or positive [0/1]
BINMINAS(d):	Binary value that arranges that MINAS N surplus in the specialised arable sector is either positive or negative [0/1]
BINMINDS(d):	Binary value that arranges that MINAS N surplus in the specialised dairy sector is either positive or negative [0/1]
BINMINPS(d):	Binary value that arranges that MINAS N surplus in the specialised pig sector is either positive or negative [0/1]
BINMINM(d):	Binary value that arranges that MINAS N surplus in mixed farming systems is either positive or negative [0/1]
BINMIPAS(d):	Binary value that arranges that MINAS P surplus in the specialised arable sector is either positive or negative [0/1]
BINMIPDS(d):	Binary value that arranges that MINAS P surplus in the specialised dairy sector is either positive or negative [0/1]
BINMIPM(d):	Binary value that arranges that MINAS P surplus in mixed farming systems is either positive or negative [0/1]
XPAMMCORR:	'Unavoidable' NH_3-N-loss, positive range [kg]
XNAMMCORR:	'Unavoidable' NH_3-N-loss, negative range [kg]
XDISDSP:	Amount of cattle slurry to be disposed of outside the dairy sector, positive range [kg N]
XDISDSN:	Amount of cattle slurry to be disposed of outside the dairy sector, negative range [kg N]
XINCARA:	Income generated in the arable sector [€]
XINCDAI:	Income generated in the dairy sector [€]
XINCPIG:	Income generated in the pig sector [€]
XINC:	Total income generated [€]
XLAB(q):	Labour requirement per two week period q [h]
XLABT:	Total labour requirement [h]
XMINASP:	MINAS N surplus in the arable sector, positive range [kg]
XMINASN:	MINAS N surplus in the arable sector, negative range [kg]
XMINDSP:	MINAS N surplus in the dairy sector, positive range [kg]
XMINDSN:	MINAS N surplus in the dairy sector, negative range [kg]

Appendix 6. (continued)

List of decision variables defined in the MGLP model

XMINPSP:	MINAS N surplus in the pig sector, positive range [kg]
XMINPSN:	MINAS N surplus in the pig sector, negative range [kg]
XMINMP:	MINAS N surplus in mixed farming, positive range [kg]
XMINMP:	MINAS N surplus in mixed farming, negative range [kg]
XMIPASP:	MINAS P surplus in the arable sector, positive range [kg]
XMIPASN:	MINAS P surplus in the arable sector, negative range [kg]
XMIPDSP:	MINAS N surplus in the dairy sector, positive range [kg]
XMIPDSN:	MINAS N surplus in the dairy sector, negative range [kg]
XMIPPSP:	MINAS P surplus in the pig sector, positive range [kg]
XMIPPSN:	MINAS P surplus in the pig sector, negative range [kg]
XMIPMP:	MINAS P surplus in mixed farming, positive range [kg]
XMIPMN:	MINAS P surplus in mixed farming, negative range [kg]
XPIG(S,F,zz):	Number of pig places in housing system S with feeding system F in stable and storage type zz [pig places]
XYS(yy,bb,nn,cc, mm,zz):	Number of cattle type yy with milk production level mm at herbage supply level cc in stable and storage type zz, kept under grassland utilisation method bb with N application rate nn [head]

Appendix 7.

Fixed costs, variable costs and other costs in dairy farming systems

		Price	Unit
Fixed costs			
Machine costs grassland			
Grazed grassland		40.56	€ cut^{-1}
Grassland used for zero-grazing		62.95	€ cut^{-1}
Grassland used for ensiling grass		206.56	€ cut^{-1}
Grassland used for hay-making		301.90	€ cut^{-1}
Grassland used for artificial drying		150.61	€ cut^{-1}
Re-sowing grassland		238.28	€ ha^{-1}
Machine costs feeding variables			
Grass silage		36.75	€ ton^{-1} dm
Hay		21.39	€ ton^{-1} dm
Fodder beet		105.44	€ ton^{-1} dm
Maize silage / CCM		37.28	€ ton^{-1} dm
GPS		36.75	€ ton^{-1} dm
Stables, slurry storage, milking equipment			
Costs attributed to dairy cows		833.36	€ dairy cow^{-1}
Extra costs low emission stable and slurry storage		99.83	€ dairy cow^{-1}
Variable costs			
Re-sowing / pesticide costs			
Permanent grassland		68.22	€ ha^{-1} yr^{-1}
Grassland in rotation		103.58	€ ha^{-1} yr^{-1}
Conservation and storage costs			
Grass silage		9.86	€ ton^{-1} dm
Artificially dried grass		90.76	€ ton^{-1} dm
Maize silage		9.86	€ ton^{-1} dm
CCM		11.06	€ ton^{-1} dm
Fodder beets		21.66	€ ton^{-1} dm
Wheat grains		2.36	€ ton^{-1} dm
GPS		9.86	€ ton^{-1} dm
Variable costs cattle			
Dairy cows		130.50	€ $head^{-1}$
Yearlings		45.89	€ $head^{-1}$
Calves		90.40	€ $head^{-1}$
Straw admixture	day-and-night grazing	13.61	€ $head^{-1}$
	day grazing	15.88	€ $head^{-1}$
	zero grazing	18.15	€ $head^{-1}$
	calves and yearlings	9.08	€ $head^{-1}$

Appendix 7. (continued)

Fixed costs, variable costs and other costs in dairy farming systems (continued)

	Price	Unit
Other costs		
Concentrates		
Low protein	170.69	€ ton^{-1} dm
Standard	173.95	€ ton^{-1} dm
Moderately protein-rich	182.77	€ ton^{-1} dm
Protein-rich	191.60	€ ton^{-1} dm
Very protein-rich	224.37	€ ton^{-1} dm
Low phosphorus	226.89	€ ton^{-1} dm
Wheat grains	149.65	€ ton^{-1} dm
CCM	170.62	€ ton^{-1} dm
Slurry disposal costs		
Cattle slurry disposal	0.74	€ kg^{-1} N

Appendix 7. (continued)

Fixed costs, variable costs and other costs in pig production systems

	Price	Unit
Fixed costs		
Stables, slurry storage		
Costs attributed to pigs in standard housing system	43.78	€ pig place^{-1}
Costs attributed to pigs in free range housing system	62.80	€ pig place^{-1}
Machine costs feeding variables		
Wheat	7.80	€ ton^{-1} dm
CCM	46.50	€ ton^{-1} dm
Variable costs		
Health management, heating, electricity, sawdust		
Costs attributed to pigs in standard housing system	4.67	€ pig^{-1} sold
Costs attributed to pigs in free range housing system	5.13	€ pig^{-1} sold
Conservation / storage costs		
Wheat	2.36	€ ton^{-1} dm
CCM	11.06	€ ton^{-1} dm
Piglets		
Piglet, standard housing system	45.91	€ piglet^{-1}
Piglet, free range housing system	61.79	€ piglet^{-1}
Other costs		
Compound feeds and other feeds		
Compound feed for phase 1	262.99	€ ton^{-1} dm
Compound feed for phase 2	226.89	€ ton^{-1} dm
Compound feed for phase 3	226.89	€ ton^{-1} dm
Supplementary compound feed for phase 1	283.61	€ ton^{-1} dm
Supplementary compound feeds for phases 1 and 2	242.36	€ ton^{-1} dm
Wheat grains	149.65	€ ton^{-1} dm
CCM	170.62	€ ton^{-1} dm
Manure and slurry disposal costs		
Pig slurry disposal	0.38	€ kg^{-1} N
Solid pig manure disposal	0.36	€ kg^{-1} N

Appendix 7. (continued)

Fixed costs, variable costs and contract labour costs in arable cropping systems

	Fixed costs	Variable costs		Contract labour costs
	machine costs (€ ha^{-1})	storage costs (€ ton^{-1})	other variable costs (€ ha^{-1})	(€ ha^{-1})
Maize silage	141.09	-	380.82	604.89
CCM	141.09	-	355.86	642.10
Ware potato	905.75	147.69	1226.95	-
Sugar beet	256.51	-	548.35	407.04
Fodder beet	256.51	-	437.26	407.04
Onion	580.57	33.69	1177.50	147.02
Pea	154.23	-	377.55	774.38
Wheat, for bread-making	200.88	-	287.12	363.02
Wheat, for feeding	200.88	-	287.12	456.05
Whole crop cereal silage	200.88	-	196.36	408.40
White cabbage	1344.87	40.63	3482.09	-

Appendix 7. (continued)

Other costs.

	Price	Unit
Land		
rent of land	442	€ ha^{-1}
Mineral fertilisers		
mineral N fertiliser	0.51	€ kg^{-1} N
mineral P fertiliser	0.91	€ kg^{-1} P
Slurry application (contract labour)		
injection cattle slurry	0.66	€ kg^{-1} N
sod-fertilisation cattle slurry	0.84	€ kg^{-1} N
injection pig slurry	0.43	€ kg^{-1} N
sod-fertilisation pig slurry	0.56	€ kg^{-1} N
surface spreading solid pig manure	0.71	€ kg^{-1} N

Appendix 7. (continued)

Revenues from arable farming, dairy farming and pig production

	Price	Unit
Arable farming		
Producer prices		
Maize silage	97.31	€ ton^{-1} dm
CCM	170.62	€ ton^{-1} dm
Ware potato	635.94	€ ton^{-1} dm
Sugar beet	51.41	€ ton^{-1} fresh
Fodder beet	152.72	€ ton^{-1} dm
Onion	86.31	€ ton^{-1} fresh
Winter wheat grains	149.65	€ ton^{-1} dm
Winter wheat straw	45.38	€ ton^{-1} dm
Whole-crop cereal silage	107.60	€ ton^{-1} dm
Pea	182.73	€ ton^{-1} dm
White cabbage	231.43	€ ton^{-1} fresh
Direct area payments		
Maize / CCM	364.30	€ ha^{-1}
Winter wheat	385.81	€ ha^{-1}
Pea	540.13	€ ha^{-1}
Dairy farming		
Producer prices		
Milk	328.04	€ ton^{-1} milk
Culled cows	489.07	€ cow^{-1}
Culled yearlings	323.32	€ $yearling^{-1}$
Culled calves	108.68	€ $calf^{-1}$
Direct area payments		
Maize / CCM	364.30	€ ha^{-1}
Pig production		
Pig at slaughter weight from standard housing system	119.74	€ pig^{-1}
Pig at slaughter weight from free range housing system	163.57	€ pig^{-1}

Appendix 7. (continued)

Nutritional values of regionally produced feeds, concentrates and compound feeds[1].

		ME	dLys	dMeth+ Cyst	P	dP	NEl	OEB	DVE	structure value
		MJ kg⁻¹	g kg⁻¹	g kg⁻¹	g kg⁻¹	g kg⁻¹	MJ kg⁻¹	g kg⁻¹	g kg⁻¹	-
Regionally produced feeds										
Wheat grains	all e's,n=1	16.29	3.0	4.6	3.7	1.8	8.59	-13	110	-0.06
	all e's,n=2	16.26	2.8	4.4	3.7	1.8	8.53	-18	106	-0.06
	all e's,n=3	16.25	2.7	4.2	3.7	1.8	8.49	-21	104	-0.06
Whole-crop silage	all e's,n=1	-	-	-	2.8	-	5.48	-15	35	2.7
	all e's,n=2	-	-	-	2.8	-	5.48	-19	34	2.7
	all e's,n=3	-	-	-	2.8	-	5.48	-22	34	2.7
Corn-cob-mix	e=1,n=1	17.44	1.4	2.8	3.5	1.4	8.08	-26	63	0.4
	e=1,n=2	17.36	1.2	2.4	3.5	1.4	7.97	-33	59	0.4
	e=1,n=3	17.34	1.2	2.3	3.5	1.4	7.95	-35	58	0.4
Silage maize	e=1,n=1	-	-	-	1.9	-	6.35	-33	45	1.6
	e=1,n=2	-	-	-	1.9	-	6.35	-39	43	1.6
	e=1,n=3	-	-	-	1.9	-	6.35	-41	43	1.6
Fodder beet	all e's,n=1	-	-	-	1.8	-	7.07	-74	72	1
	all e's,n=2	-	-	-	1.8	-	7.07	-82	71	1
	all e's,n=3	-	-	-	1.8	-	7.07	-82	70	1
Compound feeds for pigs										
Phase 1		13.43	8.9	5.2	5.9	3.1	-	-	-	-
Phase 2		13.55	7.7	4.6	4.9	2.2	-	-	-	-
Phase 3		13.30	6.3	3.8	4.4	1.9	-	-	-	-
Supplement phase 1		13.30	11.1	5.7	7.0	3.7	-	-	-	-
Supplement phases 2+3		12.30	12.4	5.8	7.4	3.2	-	-	-	-
Concentrates for cattle										
Low protein		-	-	-	3.5	-	8.11	-24	64	0.3
Standard		-	-	-	5.0	-	7.21	6	100	0.3
Moderately protein-rich		-	-	-	5.0	-	7.21	11	111	0.3
Protein-rich		-	-	-	5.6	-	7.21	28	133	0.3
Very protein-rich		-	-	-	8.9	-	7.21	83	200	0.3
Low phosphorus		-	-	-	3.5	-	7.21	11	100	0.3

[1] Values for compound feeds and concentrates are on fresh matter basis, values for wheat grains, whole-crop cereal silage, corn-cob-mix, silage maize and fodder beets on dm basis.
ME: metabolisable energy; dLys: digestible lysine; dMeth+Cyst: digestible methionine+cystine; P: phosphorus; dP: digestible phosphorus; Nel: Net Energy for Lactation; OEB: degraded protein balance; DVE: true protein digested in the small intestine.

Curriculum vitae

Julianus Frederik Frans Pieter Bos werd geboren op 7 februari 1966 in Venlo. In 1984 behaalde hij het Gymnasium-β diploma aan het collegium Marianum te Venlo. In datzelfde jaar begon hij de studie Zoötechniek aan de toenmalige Landbouwhogeschool in Wageningen. In 1990 sloot hij die opleiding af met afstudeervakken algemene en regionale landbouwkunde en veevoeding. Na zijn studie in Wageningen volgde hij de eenjarige Universitaire Beroepsopleiding Milieukunde die in 1992 werd afgerond. Van 1992 tot en met 1994 was hij werkzaam bij de Themagroep Landbouw-Milieu in Wageningen. Hij coördineerde er de organisatie van allerlei op studenten en universiteits- en DLO-medewerkers gerichte onderwijs- en discussie-activiteiten op het vlak van landbouw, milieu en natuur. In opdracht van FAO en Wereldbank werkte hij vanaf eind 1994 een half jaar bij het Internationaal Agrarisch Centrum in Wageningen aan een desk-study over interacties tussen niet-grondgebonden veehouderij en milieu. In de zomer van 1995 werkte hij kortstonding bij het Centrum voor Landbouw en Milieu in Utrecht waar hij bedrijfsmilieuplannen opstelde voor individuele melkveehouderij-bedrijven in bodembeschermings-gebieden in Noord- en Zuid-Holland. In oktober 1995 begon hij in de hoedanigheid van assistent in opleiding bij de leerstoelgroep Dierlijke Productiesystemen met het in dit proefschrift beschreven onderzoek.