Farming options for The Netherlands explored by multi-objective modelling

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Abstract

Intensive agriculture in The Netherlands has a price in the form of environmental degradation and the diminution of nature and landscape values. A reorientation of farming is needed to find a new balance between economic goals and rural employment, and care for clean water and air, animal well-being, safe food, and the preservation of soil, landscape and biodiversity. The search for farm systems that meet such multiple goals requires a systematic combination of (a) agrotechnical, agroecological and agroeconomic knowledge, with (b) the stakeholders’ joint agreement on normative objectives, to arrive at conceptual new designs followed by (c) empirical work to test, adapt and refine these under real commercial farming conditions. In this paper explorative modelling at the whole farm level is presented as a method that effectively integrates component knowledge at crop or animal level, and outlines the consequences of particular choices on scientific grounds. This enables quantitative consideration of a broad spectrum of alternative farming systems, including very innovative and risky ones, before empirical work starts. It thus contributes to a transparent learning and development process needed to arrive at farm concepts acceptable to both entrepreneurs and society. Three case studies are presented to illustrate the method: dairy farming on sandy soils; highly intensified flower bulb industry in sensitive areas in the western Netherlands; and integrated arable farming. Trade-offs between economic and environmental objectives were assessed in all three cases, as well as virtual farm configurations that best satisfy specified priority settings. In two of the three cases the mutual reinforcement and true integration of modelling and on-farm empirical research appeared difficult, but for obvious reasons. Only in the flower bulb case was the explorative approach utilized to its full potential by involving a broad platform of stakeholders. The other two case studies lacked such formalised platforms and their impact remained limited. Three critical success factors for explorative modelling are identified: to cover a well-differentiated spectrum

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of possible production technologies; early timing of modelling work relative to empirical farm prototyping; and involvement of stakeholders throughout. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

In The Netherlands, as in other parts of Europe, farmers have successfully increased crop and animal production during the second half of this century. The production methods applied to achieve this have caused substantial negative side effects: emissions of pesticides and plant nutrients into the environment, decline of biodiversity and landscape values, large water and energy consumption, the neglect of animal well-being, and accumulation of wastes. Evidently these symptoms cannot be addressed one-by-one, but call for a reorientation of entire production systems towards a more sustainable agriculture. Such reorientation should cover analyses at regional, farm, and field scales. This paper addresses the farm scale.

Sustainable farming meets a combination of socio-economic, ecological and agro-technical objectives (e.g. Harwood, 1990; Anonymous, 1995). Different interest groups attach different values to each of these objectives, and rank priorities differently. Given these potentially conflicting views of ‘what is desirable’, the search for acceptable compromises is a negotiation process between stakeholders. The actors are farmers, agro-industries, drinking water producers, and the public sector including environmental pressure groups and policy makers. The transparency of the negotiation process is largely enhanced if the consequences of priority choices are made explicit. This is a task of agricultural research in general. This paper demonstrates how systems analysis and explorative modelling can contribute.

Research has a role to play in each of four phases en route towards more sustainable farming systems (Rossing et al., 1997; Vereijken, 1997). The diagnostic phase implies the identification and analysis of problems in current systems. It also includes the explicit assessment of each of the stakeholders’ goals, leading to the formulation of an overall set of goals. Next, the design phase seeks to configure production systems so as to meet the overall objectives set for a whole farm. This is done on the basis of knowledge about components such as crops, soils, animals, etc., and their interactions. The exploration of possible designs should be broadened beyond current practices by taking into account innovative technologies at this stage, which may then bring unexpected farming systems into view. Third, promising farm designs must be tested and adapted empirically, the test phase. This means assessing the operational feasibility, economic benefit and ecological performance of proposed options through implementation of the design at experimental and commercial farms. Empirical improvement of the design then leads to one or more prototype farms. Finally, these prototypes are promoted among farmers, who will refine them to meet their specific local conditions. This systematic development of farming systems, starting from well-defined multiple objectives, was formalised and coined ‘prototyping’ by Vereijken (Vereijken, 1994, 1997). The approach, with variations, is now being applied to all major sectors of Dutch agriculture, including (organic) arable farming, open field horticulture, dairy farming, and flower bulb production.

Farm modelling can provide an effective complement to empirical work in the above sequence, for several reasons: (1) Only few selected farm prototypes can be tested experimentally; a much wider spectrum of alternatives can be inspected numerically. (2) Models allow better specification of the trade-offs between goals. (3) Expert knowledge, as applied in prototyping, is often available as ‘rules of thumb’. Databases and simulation models can largely expand, refine and formalise the knowledge utilised in the design process; this may reveal solutions otherwise omitted. (4) Whereas commercial farms are not suitable test
grounds for evaluating ‘risky’ new ideas and techniques, the consequences of such innovations can be studied ad libitum through modelling. (5) External conditions, notably the policy and economic environment, may change rapidly and can have a profound impact on the feasibility of farm configurations. The consequences of such changes can be established quickly via models. (6) Empirical prototypes are developed in a particular biophysical environment, and are co-determined by the specific ‘initial status’ of the farm; models can help generalise and extrapolate the empirical results obtained at one farm to other domains.

In short, prototyping without the support of quantitative models gives only a partial picture of what ‘desirable’ production systems could look like, now and under future conditions. The dissemination to other biophysical environments remains cumbersome, and the explicit valuation of trade-offs, e.g. nitrate loss versus farm gross margin, remains undocumented. Modesty, on the other hand, suits the modelling community because empirical work is indispensable for real progress towards more sustainable farming. In this paper we set out to demonstrate the benefits that model-based explorations can offer in the quest for the better farming systems. We will first outline the methodology, and then present three ‘Dutch’ case studies where modelling supported the search for improved farming systems. All cases address the conflict between farmers’ income and the environment: in dairy farming, in flower bulb farming, and in arable farming.

2. Methodology

2.1. Objectives and agrotechnical information

A schematic summary of the methodology is given in Fig. 1. Model-based exploration of new farming options starts with the separation of (i) stakeholder objectives and boundary conditions, and (ii) quantified agro-technical knowledge about the functioning of agricultural systems and their components. Stakeholder objectives can change with changing priorities and negotiation. Examples are the phased levels of allowed nitrogen (N) and phosphorus (P) surpluses as proposed by the Dutch government. The use of agro-technical information and, subsequently, the numerical procedure to arrive at optimal solutions are outlined below.

2.2. Agro-technical knowledge: specification of production activities

Farming systems are viewed as being composed of so-called ‘activities’ or sets of coherent operations, each set corresponding to a particular way of producing a given crop or animal product. Such a set is also referred to as the ‘production

Fig. 1. Schematic representation of the methodology followed in explorative modelling of farming systems as linear combinations of so-called ‘activities’. Activities represent crops (or animals) with specified production technologies.
technology’. To grow a wheat crop, for example, various alternative technologies may exist, each of which would define a new activity. In addition to its production technology (input) an activity is also characterised by its expected outputs, e.g. yield level, product quality, cash revenue, or nitrate lost. Thus, a specific activity may require 120 kg fertiliser-N, 7 million kg water, and 15 h of skilled labour per ha, and then produces 7 tons of wheat grain, 8 tons of straw, and 30 kg of nitrate-N emitted per ha.

Each activity contributes to one or more objectives. Objectives apply to the entire farm, e.g. the farm gross margin, or the farm P-surplus. The farm is represented as a linear combination of activities, and the objective values are calculated as the sum of the contributions made by the individual activities. The coefficients that express an activity’s contribution to an objective are called ‘technical coefficients’ or input–output coefficients. They may also express a claim laid by the activity on limited resources such as acreage or animal feed. The sum of claims is then subject to a constraint, dictated either by an a priori set value (e.g. total farm acreage), or by the on-farm production of that resource as determined by other activities (e.g. grass and maize production to meet fodder demands). Likewise, the sum of contributions to objectives must meet specified minimum (e.g. gross margin) or maximum (e.g. P-surplus) values.

The biophysical processes and economic principles that, in reality, determine the translation of inputs to outputs for a given activity are generally non-linear: the amount of pesticides required for the production of 5 t/ha of wheat grain is not equal to half the amount required for 10 t/ha. The labour cost to run a stable housing 1000 pigs is not 10 times larger than the cost for a small stable of 100 animals. These non-linearities are no hindrance to linear optimisation as long as each activity is defined with input–output coefficients wherein the non-linear behaviour is embedded. This dictates how activities are delineated. For example, wheat production at 5 and 10 t/ha are defined as two distinct activities with different coefficient values.

Clearly, the ‘resolution’ used for differentiating between activities will largely affect the possible solutions to the optimisation problem. One way to increase the resolution is to define several alternative options for each ‘aspect’ of crop management, such as crop protection, nutrient management, water management, harvesting, etc. Different sets of options (one option selected for each aspect) then represent as many production technologies. Each of these is an alternative, full specification of how a particular crop can be managed.

Innovative activities must be defined and included if we really wish to look ahead. This means that we must define new ways of crop management or animal husbandry, with the corresponding input requirements and yield levels. If these coefficients are not yet available, as is usually the case, they must be assessed on theoretical grounds. Then, target yield is taken as a starting point and input requirements are assessed by presuming the most efficient resource use locally possible (Van Ittersum and Rabbinge, 1997). This procedure can also be followed for other dependent variables such as target emissions, target income, etc. Note that such targets then refer to single activities — not to the whole farm. The target-oriented approach can provide a framework to ensure that a sufficiently wide range of technologies is defined, by starting from a range of chosen target levels.

Alternatively, farmers’ practice in the relevant location (soil type, etc.) often provides a good reference for existing technologies. The differentiation of technologies then starts with defining sensible alternative crop management options, each with corresponding amounts and species of agrochemicals, their properties, prices, etc. Such variations are created on the basis of promising results from experiment stations, or based on new insights. In this way, for example, five options for crop protection may be defined, three options for nutrient management, and two for harvesting. Potentially this set would define $5 \times 3 \times 2 = 30$ different production technologies, each with specified required inputs. Some combinations are unfeasible and are deleted.
The difficult part is to translate pre-set target yields into required inputs, or vice versa, to translate given inputs into resulting yield levels (or emission levels, etc.). For 'singular deviations' from the reference we can often rely on experimental evidence. For example, to determine the effect that omission of soil fumigation has on the yields of all crops in a particular rotation. Likewise, ample quantitative data are available to describe the responses of most crops to water and nitrogen. In some cases it is convenient to use well-validated crop growth models or static models to 'generate' the values of dependent variables. Models are helpful for the quantification of graded yield levels corresponding to graded inputs. Whether calculated by models or derived straight from experimental data, the yield attained through a given option (e.g. a specific crop protection method) is expressed on a relative scale (normally 0–1, 1 representing the yield attained under a reference technology). The combined effect of options on yield is calculated by multiplication of these relative values. Alternatively, combined effects can sometimes be calculated with the help of simulation models, following, for example, Van Keulen and Wolf (1986). Difficult to quantify are the effects that crop frequency and crop sequence (within a rotation) have on yield. Experimental evidence is usually limited, and then experts are asked to estimate correction factors.

2.3. Numerical optimisation

All defined crops, animals and production technologies together represent a multitude of activities, each of which is eligible for adoption into the farming system. Peering finally into this 'kaleidoscope' we see an almost infinite variety of whole-farm configurations, depending on the spectrum of activities considered and goals and constraints imposed. The next step is the identification of systems that best meet all requirements. This is done with the help of numerical optimisation. To tackle such problems a variety of multi-criteria methods exists (French et al., 1983; Osyczka, 1984; Romero and Rehman, 1989). Most of these (such as various goal programming methods and compromise programming) require specific target values or a priori weighting factors for the objectives. The algorithm then minimises a weighted sum of deviations of the objective function values and their respective targets, or optimises a weighted sum of the various objectives. Other methods, such as dynamic programming combined with constraint satisfaction programming (Tsang, 1993; Martin-Clouaire and Rellier, 1995) may indeed address multiple objectives but aim specifically at solving sequential decision problems, rather than time-invariant optimisation problems. For optimising land use and farming systems design the above methods are not very convenient. Multiple objectives are involved, each with their own physical units, and it makes no sense to weigh a priori economic and environmental objectives into one single function. Moreover, target values for objectives are not evident beforehand: they are usually reconsidered and adjusted after their consequences have been exposed. We use multiple goal linear programming (MGLP; De Wit et al. (1988)) for our purpose. MGLP does not require the use of a common unit to express the level of achievement of the different objectives, nor the attribution of weights. It is a suitable method to generate trade-off curves between objectives (see later, Fig. 4). These can be assessed for any set of objectives, which then gives a very complete picture of options and their respective consequences. The MGLP procedure consists of a number of optimisation rounds, in each of which a selected objective is optimised and the other objectives are used as goal constraints, with or without upper or lower bounds. The mathematical formulation of an MGLP problem is not different from LP:

\[ \text{Max or Min} \{ \text{ } \} \]
\[ \text{A } \leq \]
\[ \geq 0 \]

where is the objective function: a linear function of the production activities ( ) and their respective contributions ( - coefficients) to the objective, and \( \text{A } \leq \) representing the linear constraints with the right hand side . \( \text{A} \) is an \( \times \) matrix with input–output coefficients. Only one single objective function is selected from the
multiple objectives and optimised during each one of many ‘runs’, the other objectives serving, mathematically, as goal constraints. In this alternating fashion each objective is optimised in turn. If this is done in an iterative cycle under gradual tightening of the constraints it shows which objectives are conflicting, to what extent they are, and why this is so. Ideally, this phase is interactive: stakeholders propose the tightening or loosening of constraints and discuss the consequences. MGLP has been applied for land use optimisation problems not only in the Netherlands but also in the EU (Rabbinge and van Latesteijn, 1992), Germany (Henrichsmeyer et al., 1998), Costa Rica (Castro and Ruben, 1998) and various Asian countries (Roetter et al., 1998).

2.4. Software components

In terms of software, three basic components constitute the ‘toolkit’ needed for this approach: 1. an information system that contains data describing the attributes (properties) of soils, crops, animals, crop and animal products, pests, feeds, manures, fertilisers, pesticides, machinery, fuel, labour, etc.; 2. algorithms to combine this information into technical coefficients that quantify the contributions of each discrete activity to the respective objectives; these algorithms are referred to as ‘technical coefficient generators’ (TCGs) and may include tabulated numerical information, dynamic simulation and static models; 3. the linear farm optimisation model.

3. Three cases of intensive farming

The above approach was applied over the past 5 years to three sectors of Dutch agriculture: dairy farming (Van de Ven, 1996), flower bulb production (Jansma et al., 1994; Rossing et al., 1997), and integrated arable farming (Habekotté and Schans, 1996). We summarise those studies here; for further details the reader is referred to the original papers.


Dairy farming contributes significantly to environmental pollution in The Netherlands, mainly because of high N and P emissions into groundwater and surface waters. Aarts and Middelkoop (1990) showed that in The Netherlands only 17% of the annual farm N input of 470 kg/ha leaves the farm in agricultural products, mostly in milk (64 kg N). P surplus is about 30 kg/ha per year. Nutrient budgets are, therefore, central to all attempts to develop environment oriented dairy systems. Economically profitable farming under constrained nutrient budgets is more difficult on sandy soils than on other soil types. To address this problem, farm level studies based on prototyping and explorative modelling started in 1991 in the Eastern Sand District for drought-sensitive sandy soils.

The Dairy Farming Model (Van de Ven, 1996) takes into account both economic and environmental objectives: milk output, labour income, nitrate leaching, ammonia volatilisation, and total N and P surpluses. A database and simulation models were used to generate technical coefficients for a large number of activities, taking into account the specific biophysical conditions of the above district. Grass production techniques were specified for three cattle types (dairy cow, yearling, calve); three grassland utilisation techniques (zero grazing with and without supplementary maize silage; full time grazing without supplements; and daytime grazing with supplements); eight N fertiliser levels ranging from 100 to 450 kg N per ha; three diet compositions, i.e. ratios of roughage to concentrates; and three milk production levels (5000, 6500 and 8000 kg/cow). In addition, grass harvested for winter feeding could be conserved as silage, hay or artificially dried grass, the latter representing a good concentrate. All these options were combined to yield hundreds of production technologies to utilise grassland. Unrealistic combinations were eliminated. Likewise, maize and fodder beet production and conservation methods were generated by varying yield targets, N-content-in-feed targets, N-supply to crops (ratio of slurry to chemical fertiliser), and
application techniques for slurry to crop land (injection versus broadcast application, followed or not followed by immediate ploughing) and for chemical fertilisers (placement in rows or broadcast). Introduction of catch crops after maize was optional. Options were also defined for the type of silage produced from maize: whole-plant or ground ear silage. Further, maize could be grown continuously, or in rotation with fodder beet. These options, again, allowed us to define many different ways of feed production, each with its specific set of technical coefficients expressing the contribution to labour income (gross income minus all variable and fixed costs), ammonia loss, nitrate leaching, etc. Other farm elements varied were the design of stables and slurry storage facilities, both affecting ammonia loss. The dairy farming model was used to compose whole farming systems from these elements, to explore 'the playing field' under given sets of constraints.

Experimental prototyping started simultaneously in 1991 at the De Marke farm near Hengelo in the Eastern Sand District (Van Keulen et al., 1999). The 55 ha demonstration farm has a quorum of 680 Mg of milk. It aimed to meet the national environmental standards as set, at that time, for the year 2000: nitrate concentration in subsoil percolation water less than 50 mg/l, and a reduction of 70% in ammoniacal N-loss compared to the 1980 reference level. These figures were translated for local conditions into a limit of 34 kg N/ha lost annually through nitrate leaching, and 30 kg N through ammonia volatilisation. Dairy farms can meet these standards by lowering milk production per ha, i.e. by extensification. At a given farm milk quorum, this would imply that per farm acreage must increase. This is difficult because of high land prices and a strong tendency to use agricultural land for nature development and urbanisation. Research at De Marke, therefore, addresses the production–environment conflict by optimising nutrient use while maintaining a high milk production per ha. The target annual output of De Marke was 12 Mg milk/ha, as common for commercial farms in the Eastern Sand District. The farm further aimed at an annual P-surplus below 0.5 kg P/ha, and N-surplus below 128 kg/ha.

The Dairy Farming Model was used to support prototyping at De Marke (Van de Ven and Van Keulen, 1996). Various objectives were optimised consecutively, while the system was subject to the same constraints as specified above for nitrate and ammonia losses, and P-surplus. Criteria for feed and manure balances were also taken identical to those at De Marke: all roughage utilised is produced on-farm, and all slurry produced is utilised on-farm. Other constraints were that no land is rented, N and P requirements of crops and energy and protein requirements of animals are met, and total dry matter intake by animals can not exceed their physiological limit. The other constraints adopted at De Marke (absolute milk output and maximum total N surplus) were omitted from the formal optimisation problem.

Results of the model showed that the objectives can be achieved with the farm configuration developed at De Marke, but also with very different farming systems. Fig. 2 specifies several combinations of land use, all of which meet the constraints outlined earlier. They differ, however, because they resulted from optimisation under different priorities. The optimum found when priority is given to minimal N-surplus appears similar to the De Marke system. Labour income, then, is comparatively low, as at De Marke (Fig. 3). The high income reached when P surplus is minimised (Fig. 3) is associated with high milk output.

The optimal solution for maximised labour income has all the land in grass (73% for fresh consumption, 27% for silage), with day-and-night grazing, and with an N-input of 300 kg per ha. The number of animals is 1.62 cows, 0.5 calves, and 0.4 yearlings per ha. Annual milk production is 9500 kg/cow, totalling 15.4 t/ha per year. Cows receive 2250 kg concentrates per head per year. Low-emission stables and slurry storage facilities are used. The total N surplus is 270 kg/ha per year, and labour income is Dfl 4380/ha.

The many intermediate results cannot be listed here. To mention only one: minimising ammonia volatilisation results in the same cropping pattern as maximising milk production: 15–20% of the land area in maize, the remainder in grass, with cows stabled continuously. But milk production is 12 t/ha in the first case with 250 kg N applied per
Fig. 2. Optimal allocation patterns of farm land to crop activities as calculated by the Dairy Farming Model, under different priorities: minimum N-surplus, minimum P-surplus, minimum ammonia volatilisation, minimum nitrate leaching, maximum labour income, and maximum milk production. The top bar represents the actual land use pattern at the ‘De Marke’ experiment farm.

ha per year, whereas 17.7 t milk output is attained in the second case, with 350 kg N input per ha.

The model helped evaluate some aspects of the system lay-out at De Marke. It showed that producing more than 25% of the required feed concentrates on-farm is costly and reduces total milk output. While introducing maize cultivation on up to 20% of the total farm acreage gave a slight reduction in maximum labour income, a further increase to 30%, as at De Marke, reduced income by almost 15%. In return, N-surplus and the N input/output ratio decreased. The study showed that several different configurations are as good as, or better than, the actual experimentally developed farm. Many more aspects can be inspected based on the model results. Such analysis provides a basis for further scientific discussion and exploration of alternative development possibilities for dairy farming on sandy soils.

Fig. 3. Labour income as calculated by the dairy farming model, under different priorities: minimum N-surplus, minimum P-surplus, minimum ammonia volatilisation, minimum nitrate leaching, maximum labour income, and maximum milk production. The top bar represents labour income at the De Marke experiment farm.
3.2. Case II: flower bulb farming

The flower bulb sector in the Netherlands, with 17 000 ha representing a flourishing branch producing 1.5 billion Dfl of annual export value, is a heavy burden on the environment. Current systems use large amounts of nutrients and pesticides per unit area. Nutrient surpluses were estimated at 230 kg N, 100 kg P₂O₅, and 170 kg K₂O per ha per year (Weel et al., 1995). The level of pesticides input has been estimated at 120 kg of active ingredient (a.i.) per ha per year (Anonymous, 1991).

Pressure groups confronted bulb growers in 1990 by calling public attention to the industry’s impact on the environment, and calling on consumers to halt current production practices. A group of young bulb growers responded by establishing the ‘Bulb Forum’, a dialogue platform aiming to collectively set the outline for a sustainable bulb industry. Soon a lack of quantitative insight on trade-offs between income and environment hampered further communications. The forum initiated a project to: (i) define the bottlenecks facing the sector, (ii) evaluate the technical options at the growers disposal to realise environmental and economic objectives at farm level, and (iii) enable a transparent dialogue by making the consequences of proposed choices explicit. The project employed the above methodology (Rossing et al., 1997), using the MGOPT-CROP model (Schanz, 1996). The study synthesised fragmented agronomic information and explored the options for flower bulb production systems with a time horizon of 10–15 years. It focused on farms on the coarse sandy soils overlying shallow groundwater in the western part of The Netherlands. The objectives agreed upon by the Bulb Forum were gross farm margin (to be maximised), pesticide input (kg a.i. averaged over total cropped area; to be minimised), and N surplus (to be minimised; defined as N-input minus N-output in the form of products).

Specific for this case study was the emphasis on soil borne diseases and their effects on crop yields. Damage is much affected by the sequence of crop species and by the frequency of each crop in the rotation. Damage from soil borne diseases, and also the transfer of nutrients in crop residues to the subsequent crop, can be influenced by so-called ‘inter-crop activities’ such as soil fumigation, soil inundation, and prevention of wind erosion with straw, all common practices in bulb cultivation. Other options to alleviate disease pressure are the rent of foreign ‘healthy’ land, and the use of winter wheat as a ‘break crop’ to improve soil structure and soil health. All these agronomic options were allowed in the optimisation procedure.

The MGLP model was to compose optimal crop rotation systems from a large set of ‘crop activities’, each with their specific production technologies and quantified effects of soil-borne diseases from preceding and on subsequent crops. ‘Crop activities’ were defined for tulip, narcissus, hyacinth and lily. Each crop activity was characterised by five aspects: soil type (sand or clay soil), soil health (three levels of disease pressure), cropping frequency (seven levels), crop protection regime (five packages) and nutrient regime (six N input levels). Thus, more than 600 hypothetical production technologies were considered in the optimisation phase for each crop–soil combination. The specification of activities was not only based on current practices but included also available experimental technologies. This broadened the scope for new farm configurations. The algorithms to generate the corresponding technical coefficients were based on experimental data, expert knowledge, and production ecological theory (Jansma et al., 1994; De Koning et al., 1995; Van Itterssum and Rabbinge, 1997).

The trade-offs between income and environment were explored by maximising farm gross margin at increasingly tighter constraints on pesticide use and N surplus. The results of the calculations with the MGLP model are depicted in Fig. 4. Point A in this figure represents a reference farm configuration that just meets the government targets as anticipated in 1994, with respect to pesticide input and nitrogen surplus for the year 2000. This implies: (i) annual nutrient surpluses no more than 25 kg P₂O₅, 50 kg K₂O, and 140 kg N per ha, averaged over the farm area; (ii) a
maximum pesticide input of 48 kg a.i. per ha, which represents a reduction of 60% down from the 1989 sector mean; and (iii) limitation of soil fumigation to once per 5 years at maximum. Farm gross margin was calculated as financial returns minus allocated costs of hired labour, pesticides, fertilisers, and contract-machine use. Investments in farm infrastructure were not taken into account.

Iso-lines in Fig. 4 express a gross margin index, a value of 100 referring to farms that just meet the environmental constraints. The index value is zero when gross margin equals zero. The absolute gross margin at the index value 100 was Dfl 205 000 per ha. Starting from a farming system represented as A in Fig. 4 two paths depict the evolution of maximised gross margin under constraints of gradually reducing pesticide use and N-surplus. The evolution for pesticide reduction (A–B–C–D) shows that a substantial reduction in pesticide input may be reached initially (A–B), with farm gross margin rather stable (index = 97 at point B). This is achieved by substituting soil fumigation by inundation, and by adopting new low-dosage fungicides in tulips. No changes occur in the cropping sequence nor in the rented land acreage. Further reduction in pesticide input (B–C) is most economically accomplished by abolishing the use of mineral oil for virus control in lilies. The associated yield loss in lily causes a decreased farm gross margin at point C (index = 77). Again, no changes in cropping pattern occurs. The third step, to zero pesticide input at D, causes major changes. The rotation changes from tulip–lily–wheat to narcissus–wheat and farm gross margin becomes negative (index = −4 at D). The area of rented land free of soil-borne pests and diseases remains approximately 11 ha at all stations. Tulips are grown on this rented land, with a relatively modest pesticide input of 12 kg a.i./ha.

The line A–E–F–G in Fig. 4 shows that considerable income loss results from measures to...
reduce farm N-surplus, already at the transition A–E. Decreasing N-surplus by 30% leads to a 40% drop in farm gross margin. In the crop rotation corresponding to point E narcissus has replaced lily. Narcissus has a higher N-efficiency but much lower gross margin than lily.

Among the unexpected results of this explorative study was the conclusion that adoption of winter wheat in the crop rotation, and the renting of fresh land are promising strategic options to reconcile income and environment. Earlier expectations of the Bulb Forum focussed rather on fine-tuning nutrient management and crop protection in current crops.

Further, results from experimental farms and current trends in the sector support the conclusion that reducing pesticide use is easier — in terms of farm income — than decreasing N-surplus. Remedy may be sought in developing new technologies, aiming at more precise application of nutrients in time and space, or in re-evaluating such strategic choices as growing the bulk of nutrient-inefficient flower bulb crops on sensitive alluvial sands. As a result of the study the forum formulated with collective support the ‘Bulbs beyond 2000’ initiative for integrated production. The first group of commercial growers switched to integrated farming methods in 1998.

3.3. Case III: integrated arable farming

Whereas arable cropping in The Netherlands is relatively clean compared to the dairy and flower bulb sectors, it generally uses nutrient and pesticide inputs high enough to cause undesirable side effects: eutrophication of surface waters, and increased purification costs in the production of drinking water (Anonymous 1996a,b). The average annual surplus of 170 kg N/ha arable land may be far less than its equivalent on grassland, but it is much higher than values found in most other European countries. The use of pesticides has reduced drastically since the multi-year crop protection plan (MJP-G) became effective in 1991, but reductions by 1995 were still largely confined to soil fumigants (remaining input of 3 kg a.i./ha), leaving the total inputs of fungicides (5.6 kg/ha), herbicides (5.0 kg/ha) and insecticides (0.7 kg/ha) virtually unchanged (Lotz et al., 1997).

Integrated farming systems aim to fulfil several objectives simultaneously: moderate inputs of agrochemicals, room for nature and landscape values and sufficient income. Emphasis then moves from yield maximisation to cost reduction and improved quality of produce and production processes. Where possible, biocides are replaced by knowledge-intensive (but sometimes also labour or capital-intensive) non-chemical methods and nutrient management strategies aim at high efficiency. A project was launched to introduce integrated arable farming methods via prototyping among ‘innovative’ commercial arable farmers (Wijnands, 1992). Explorative modelling at farm level became available at the time and the model MGOPT-CROP was developed to accompany the on-farm work (Schans, 1996).

The study focused on two regions: the central marine clay district (CZK, the Flevoland area) and the north-eastern reclaimed peatland district (NON) where sandy soils high in organic matter remained after the peat layer was removed in historic times. The numerical characterisation of ‘crop activities’ based on technology packages was as described for the flower bulb study. This characterisation was done for all crops grown at the innovation farms: ware potato, seed potato, starch potato, sugar beet, fodder beet, five small grain crops, maize, grass seed, onion, carrot, cabbage, chicory, pea, faba bean, rye grass, alfalfa and clover. To reduce the optimisation process only a selection of crops was considered in the model study: ware potato, starch potato, sugar beet, winter wheat, maize, onion, and grass seed. Fallow was also included as an ‘activity’, as were other ‘inter-crop activities’ such as the application of organic manures and the cultivation of catch crops and green manures (Habekotté, 1994; Habekotté and Schans, 1996). Only two crop protection options were defined, for each crop.

The objective variables were gross margin (as defined for the bulb study), kg N loss per ha, and input of pesticides (kg a.i./ha). The N-loss was estimated as mineral N-input (in chemical and organic manures) plus net amount of N released by mineralisation (per whole year) minus N re-
Fig. 5. Maximum gross margin per ha for arable farming on clay soil under constraints on pesticide input (kg a.i./ha) and nitrogen loss (kg N/ha) for 1992–1993 price levels including EU support regulations. Letters A, B and C refer to rotation schemes shown in circles (right), where shading refers to intensive crop protection regimes.

moved in crop produce, minus N transferred to the next season through catch crops, green manures and crop residues.

The trade-offs between farm economy and the environment as exposed by MGOPT-CROP calculations were similar to those discussed above (Fig. 5): shallow gradients around the point of maximum gross margin, both in the direction of decreasing N loss and decreasing pesticide input. Gross margin dropped abruptly if the constraint on allowable N loss was tightened from 100 to 60 kg N/ha, in the CZK district. In both the CZK and NON districts the reduction of N-loss could be achieved through: (i) a replacement of organic by chemical fertilisers, (ii) lowering N-supply to match deliberately lower-set target yields, and (iii) changing the cropping pattern. Options (ii) and (iii) lead inevitably to a reduction in farm gross margin. Reduced biocide input appeared to be possible without major losses of gross margin, especially in the NON region, by eliminating soil fumigation. Dramatic income losses were calculated, however, when biocide inputs were further reduced below 5 kg a.i./ha. This forced drastic changes in cropping pattern.

These findings provide clear answers, at least for arable farming in the regions studied, to an often raised dilemma: should farmers change cropping patterns or choose for 'sub-maximal' use of agrochemicals in the existing cropping pattern, when their aim is to meet both economic and environmental objectives? These explorations pointed clearly towards the latter option. Only as a last resort should the share of cereal crops in the rotation be increased. Where these conclusions are in contrast with the flower bulb study, it must be noted that bulb farming is far more intensified than arable farming.

4. Lessons learnt

The above experiences taught us that at least three conditions must be met if modelling is to make a real contribution in the search for improved farming systems. First, a sufficiently wide gamut of production technologies, including really innovative packages, must be specified and supplied as the basis for the optimisation phase, i.e. as building blocks for possible adoption into
the optimal farm configuration. Only then can numerical optimisations open up avenues not yet obvious on practical grounds. Second, explorative modelling efforts must deliver the farm designs already at an early stage of empirical research to assure mutual enhancement of theory and practice. Once empirical prototyping has started tactical and operational — rather than strategic — issues tend to dominate the work on further developing the selected farming systems. Last but not least, a third condition is the involvement of interest groups throughout the project from its definition phase up to the interpretation and implementation of the results.

The potentials of modelling were exploited well in the flower bulb study. Many crop cultivation options were defined outside the domain of current practices. A project with forerunner farms was to start only much later, which rendered the model-based explorations timely and innovative at the time. Various stakeholder groups were directly involved and the explicit distinction between normative objectives and bio-physical knowledge was appreciated by both growers and environmentalists. While the a priori outlook of growers focused on tactical decision making, the study showed the importance of strategic choices in mitigating loss of farm gross margin under tightening environmental constraints. Despite uncertainty in a number of agronomic relationships the results were deemed sufficiently robust for testing and improvement on commercial farms. Such follow up started in 1998.

The contribution of modelling to prototyping differed considerably between the three cases discussed and this was partly due to its timing relative to experimentation. In contrast to the bulb case, experimental work in the arable and dairy farming studies quickly set out its own course, and the impact of modelling remained limited. Ready-to-use databases and simulation modules are indispensable to assure timely delivery of theoretical prototypes. The time needed to establish these tools is easily underestimated.

The Dairy Farming Model indicated that the real layout of the De Marke farm was not necessarily optimal, although it satisfied all targets. Income could be further maximised without violating the constraints adopted at the outset. Such findings should trigger further in-depth research to confirm feasible options to improve the real farm. At the moment it remains an open question whether explorative modelling can fulfil its promise to help extrapolate the De Marke findings to commercial farmers. The coming years will see the outcome, as representatives of ‘clusters’ of dairy farms — groups similar in biophysical setting and socio-economic aspects — have started a new phase in 1999.

In the arable farming study forerunner farms often performed better than the optimised virtual farms. Among the causes for this discrepancy was the underestimation of crop production for given production technologies, i.e. the numerical values attributed to technical coefficients. Real on-farm yields were higher than those modelled for seed potato and sugar beet (CZK, NON), onion (CZK), and starch potato (NON). These deviations are crucial, as the exact yield levels of high-value crops largely determine the feasibility of any farm configuration. Another cause was the trimming of the list of considered crop activities (crops and production technologies) for reasons of computation time. Many feasible configurations were thus eliminated from the solution space. Such flaws, combined with delayed availability of model results, restricted the acceptance of modelling as a support tool in prototyping arable farms. A follow-up to this project starts in 2000 with a network of commercial integrated arable farmers aiming to meet stringent norms on N and P surplus on a variety of representative soil types of the Netherlands.

It remains difficult to evaluate the quality of the outcomes of explorative models. This is due to the large number of variables and coefficients involved. There is a need for formalised protocols to quantify uncertainty in the numerical solution of MGLP problems (‘which other farm types are about as good?’) and in the associated objective function values. Attractive farm designs obtained through modelling should lead us back to trace and verify all steps made to arrive at this result. Finally, a form of validation is to test experimentally the proposed farm configurations as a whole. While this is difficult and costly these drawbacks
are precisely the main justification of modelling: to limit experimental work to the most promising designs.

5. Conclusions

Three critical success factors for explorative modelling are: to cover a well-differentiated spectrum of possible production technologies; early timing of modelling work relative to empirical farm prototyping; and involvement of stakeholders throughout the study. Of these conditions explorative modelling helps to display broad perspectives of possible farming system configurations, to assess their achievements in terms of goal variables, and to quantify the trade-offs between objectives. The analysis must utilise the best available component knowledge to survey the whole playing field and thus help understand the system’s potentials.

The approach fulfils a rather strategic role in the prototyping process because it does not indicate development trajectories departing from a ‘current starting point’. Instead it identifies most desirable ‘target systems’. The quality and usefulness of such designs depend on the prior availability of a sufficiently wide array of technological options with properly quantified coefficients. Better research programming linking modelling and on-farm work will mean that interesting theoretical options are quickly evaluated in practice, and that experimental work can be devoted to quantifying the relevant coefficients with sufficient accuracy. Modelling can only provide an effective support if such feedback is deliberately created. Similarly, component research (on crops and animals) on the one hand, and farm-level research on the other could benefit from such mutual feedback.

Explorative studies can be called successful if they enhance the process of separating fact from opinion in the participants’ minds, if they enable sound discussion based on sound arguments, and if they bring new viewpoints into a sometimes polarised debate. All this requires an intense involvement of the actors in the decision field. To establish and guide this process is perhaps the most difficult task on the way to improved farming systems. Whereas, so far, researchers were always an intermediary between model and end-user of model outputs, the debate may well be better served if models are presented in the form of self-instructive ‘playing tools’, for direct use by the actors. Ultimately, such interactive tools may also be helpful in the dissemination phase to assist adaptation and adoption of balanced and tested farm concepts in practice.

References


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