OPTIMIZATION OF FORAGE PRODUCTION IN INTEGRATED DAIRY FARMING SYSTEMS

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Abstract

The aim of the study described in this paper is to explore the possibilities for integrated dairy farming, taking into account both environmental and economic goals, so as necessary to obtain a realistic impression of those possibilities.

The approach presented is a step from the technical side towards filling the gap between agrotechnical and economic analyses. Interactive Multiple Goal Programming is used as optimization technique. Various environmental and economic goals are optimized using a mix of production techniques subject to a set of constraints. The production techniques are defined by quantifying the relevant inputs and outputs.

From the set of production techniques selected in the optimization, priorities for research and development of integrated dairy farming systems can be derived. The next step is to insert promising sets into a national model and, applying the same procedure, determine how the results fit in on the national scale. A thorough analysis of the results permits examination the scope for future developments in dairy farming. Further analysis is required to assess the policy measures necessary to guide introduction or development of favourable production techniques.

INTRODUCTION

Agricultural development is guided by technical and socio-economic possibilities and by the objectives that are pursued. The development of very intensive and specialized agricultural production systems has led to increasing pressure on the environment. Until recently, objectives like environment and landscape/nature/scenery, were not explicitly taken into account, as the main priorities were income and employment at farm level and low-cost agricultural products for society. A consequence is serious pollution of soil, water and air, partly caused by the present agricultural practices. With integrated agriculture a more balanced situation is aimed at. It can be defined as a sustainable, technically highly developed way of agriculture, which, compared to current agricultural practices, uses less energy and other resources, pollutes the environment less, provides more employment, provides a remuneration of labour and capital at parity with other sectors in society and, in addition to agricultural products, produces an attractive landscape (Van der Weijden et al., 1984).

In this study special attention is paid to forage production and utilization on dairy farms, because the related environmental problems are of a more complex nature than those related to intensive animal husbandry. Both animal production systems and plant production systems have their own specific environmental effects, which are combined in dairy farming. In integrated dairy farming, forage production systems should provide the livestock with sufficient fodder of a satisfactory quality to produce the required amount of milk, should absorb the manure produced by the animals and should restrict environmental pollution.

Although legal restrictions on application of animal manure on agricultural land are based on normative values for phosphorus, nitrogen (N) causes the major environmental problems in Dutch dairy farming. An analysis of the nutrient balance of a large number of dairy farms showed that only 14% of the N imported into the production system each year leaves the farm in agricultural products (Aarts et al., 1988; Van der Meer, 1985). Chemical fertilizers and concentrates account for 83% of the inputs of N and milk for 83% of the outputs. The difference between N inputs and outputs of 470 kg ha-1 yr-1 causes environmental problems due to leaching of nitrate and volatilization of ammonia and nitrous oxide, if it is not accumulated in the soil nor denitrified to elementary N.

The main aim of this study is to explore the possibilities for alternative production systems from both the environmental and economic point of view.

Both economists and agronomists approach agricultural development from their own specific point of view, using their own language and research tools. Their approaches generally are so different, however, that often communication and exchange of results is difficult. To obtain a realistic view of the possibilities for agricultural development, however, both approaches should be integrated. The approach presented here is a step from the technical side towards filling the gap between agricultural and economic analyses. By using input-output models as a starting point, as is done frequently in economics, the results of the technical analyses are presented in such a way, that their use by economists and policy makers is facilitated. Economic constraints are taken into account, but behavioural relations are omitted.

Often, different technically feasible development paths are possible that satisfy different goals to a greater or lesser extent and the 'trade-offs' between different goals determine the degree of compromise that can be reached. The development plan that is finally implemented reflects, implicitly or explicitly, the relative importance attached to the various goals. All possible environmental and economic goals and constraints imposed on dairy farming should be taken into account to arrive at a satisfactory set of production systems.

APPROACH

To investigate the different possibilities, Interactive Multiple Goal Programming (IMGP) is used as an optimization technique. IMGP is a multi-criteria decision method, which can easily be combined with linear programming (Spronk and Veeneklaas, 1982). Goals are optimized using a mix of production techniques subject to a set of constraints. The production techniques are defined by quantifying their intended and unintended outputs and their required inputs. All production techniques are defined in a target-oriented way. The production target is defined first and then all associated inputs and outputs are quantified. The inputs utilize resources that are limited and may therefore be constraining for the scale at which production techniques can be realized.

The degree to which a goal is realized is expressed by the value of a goal variable. In the optimization process, in one iteration each of the goals is optimized individually, while on the values of the other goals variables restrictions are set. A goal restriction represents the most unfavourable value of a goal variable. By tightening the goal restrictions in successive iteration cycles, i.e. improving the most unfavourable values for the goal variables, the feasible area is reduced and so are, in general, the best attainable values. During the procedure, the user of the model can express his preferences and becomes aware of the costs of better satisfying one goal in terms of the others. Finally, a situation is reached where one cannot improve on any of the goals, without sacrificing on the others. The results show a feasible combination of the values of the goal variables, and the associated mix of production techniques.

By emphasizing different goals during the optimization procedure different sets of production techniques are likely to be selected. Different users end up in different corners of the feasible area. For a more detailed description of IMGP and its application in agricultural planning, reference is made to Van Keulen en Van de Ven (1988) and to De Wit et al. (1988).

All production techniques formulated should be technically feasible, but that does not mean that they are actually applied on farms. They may still be in the research and development pipeline or they may not have been implemented due to domination of economic goals over environmental ones up to the present.
It is, however, important to consider all possible production techniques that could offer opportunities for the future, which means that one should be careful not to be biased towards any production technique, so no perspectives for development are blocked in advance. Quantification of production techniques that are not yet practised on farms in terms of their inputs and outputs may be difficult due to lack of detailed knowledge, but then it is preferable to make a best possible estimate rather than to omit them. From the selected set of production techniques priorities for research and development can be derived.

A question that remains unanswered, when the IMGP procedure is applied to integrated dairy farming with its specific environmental and economic goals, is how the results fit in on the national scale. How much does dairy farming affect national environmental and economic goals? The importance of dairy farming in the national context partly determines the development possibilities.

To solve this problem Veeneklaas (in prep.) suggests to apply a two-stage optimization procedure. In the first stage IMGP is applied to integrated dairy farming with its sector-specific goals. The goal restrictions are not set too tight, but leave a rather large feasible area. That implies that for each of the goals a relatively favourable value can be achieved, which may, however, be at the expense of the values obtained for the other goal variables. From this large feasible area several promising and relevant sets of production techniques are selected by further optimizing one of the goals. Each set represents a different technically feasible scenario for integrated dairy farming. Knowing the mix of production techniques in each scenario, these scenarios can be described in terms of inputs and outputs and inserted in a national model as a separate sector. Then the subsequent optimization procedure, again IMGP, can be executed with national goals, the scenarios now becoming instruments to reach those goals. In this way the output of the first optimization round serves as input for the second optimization round. The results of the latter will contain the most favourable dairy farming production techniques with respect to both national and sector-specific goals and the importance of the dairy farming sector and its contribution to national goals can be derived. For a more theoretial background and a detailed description of two-stage optimization, reference is made to Veeneklaas (in prep.).

The remainder of this paper describes the planned application of the two-stage optimization to forage production in integrated dairy farming.

FORAGE PRODUCTION IN INTEGRATED DAIRY FARMING

GOALS

The goals defined for integrated dairy farming are classified into quantifiable and non-quantifiable ones and the goals with the highest priority are listed in Table 1. Forage production is not a goal in itself, but serves animal production. Therefore, it is taken into account indirectly in the goal 'restricted production of milk and meat'.

The non-quantifiable goals are not optimized using IMGP, but after applying IMGP the selected production techniques will be screened critically with respect to their contribution to those goals. If the limits of one or more goals are exceeded, the results should be adjusted by excluding the responsible production techniques from the

Table 1. Goals in integrated dairy farming.

QUANTIFIABLE GOALS
ENVIRONMENTAL
- minimize nitrate leaching
- minimize ammonia volatilization
- minimize the surplus of animal manure
SOCIO-ECONOMIC
- maximize profit
- maximize paid employment of the farmer and others
- restricted production of milk and meat
NON-QUANTIFIABLE GOALS
- produce a landscape as attractive as possible
- maximize the well-being of animals

solution set.
It is possible to optimize goals that can be arranged on an ordinal scale, but not directly quantified, using IMGP, but that is not considered at this stage of the project.

PRODUCTION TECHNIQUES

Dairy farming systems exist of an animal production and a forage production part. For both parts technically feasible production systems, which are only in part actually practised, are identified.

Forage comprises both grass and other fodder corps like silage maize, fodder beet and fodder grain. For each of those crops several production techniques have been defined, characterized by production level. Four production levels have been selected for grass and two for each of the other crops. Additionally, various grassland management methods are distinguished, characterized by different stocking rates, grazing systems and cutting regimes. Stocking rate does not strictly depend on production level as additional feed can be purchased.

Three main defoliation systems are distinguished, two grazing and one non-grazing sytem. When forage feeding is applied and the cows are inside year-round, the grass is only cut. If only day time grazing or day and night grazing is practised, one cut is taken for conservation for winter feeding and the remainder is grazed. Each variation in one of those characteristics results in a separate production technique, with its associated inputs and outputs. The main inputs and outputs for forage production systems, as relevant for the goals defined, are summarized in Table 2.

Table 2. Inputs and outputs of forage production systems expressed on an annual basis.

INPUTS	unit	OUTPUTS	unit
chemical fertilizer (N,P,K)	kg ha-1	herbage - dry matter	kg ha-1
animal manure (N,P,K)	kg ha-1	- energy	MJ ha-1
labour - farmer	h ha-1	- protein	kg N ha-1
- hired	h ha-1	nitrate leaching	kg N ha-1
variable costs	fl ha-1	ammonia volatilization	kg N ha-1
fixed costs	fl ha-1	denitrification	kg N ha-1
land	ha ha-1	N accumulation	kg N ha-1
N deposition	kg N ha-1		

To quantify inputs and outputs for grass production, it was necessary to integrate knowledge available from experimental work in the Netherlands and data from literature and experts. Due to the bulk of data, the easiest and most consistent way to do so was to develop a model, an expert system. Once that expert system was developed, it was relatively simple to calculate inputs and outputs of the grass production systems defined, especially of those that are not practised yet.
For the other fodder crops the same sources have been consulted, but no expert system was constructed because of the relatively small amount of data that had to be collected.

Six animal production systems have been distinguished, characterized by milk production level and grazing and cutting regime. Of course, the three defoliation systems defined here correspond with the ones defined for grassland management. Two milk production levels have been defined to start with. The main inputs and outputs are listed in Table 3.

Table 3. Main inputs and outputs of animal production systems, expressed on an annual basis.

INPUTS	unit	OUTPUTS	unit
feed requirements		milk	kg cow-1
- energy	MJ cow-1	meat	kg cow-1
- protein	kg N cow-1	manure (N,P,K)	kg cow-1
- fibrous material	-	ammonia	
maximum dry matter intake	kg cow-1	volatilization	kg N cow-1
concentrates	kg cow-1		
labour	h cow-1		

Special attention is paid to the N flow through the systems, as N causes the major environmental problems. The losses of N due to grazing are rather large, as grazing enhances both ammonia volatilization and nitrate leaching from the grassland due to excretion of urine and faeces. When part of the manure is collected inside and cows are supplemented, however, it depends on the N content of the supplements and the method of manure storage and application which system has the best overall performance in terms of minimizing environmental pollution.

Tables 2 and 3 show that manure and forage are intermediate products, that are produced in one part and utilized in the other part of the dairy farm. In the input/output model a separate part is defined to transfer those intermediate products from one part to the other, taking into account the associated losses. For instance, different grazing losses occur under the different grazing systems, although the same gross production may be realized. In this third sector also three methods for application of manure have been distinguished, surface spreading with and without sprinkler irrigation and injection. Those methods are characterized by a different nitrogen uptake by plants as fraction of what is applied.

The input/output model is quantified on an annual basis. That means that an equilibrium situation is assumed and the results of the optimization procedure can be considered the end of a development path. The production techniques are defined in such a way that they are sustainable, i.e. do not exhaust non-renewable resources.

CONSTRAINTS

The goal restrictions can be derived from Table 1. For each of the goals listed below an upper or lower limit in case of minimization or maximization, respectively, is defined.

- environment:
  * nitrate leaching should not exceed an upper limit;

  * ammonia volatilization should not exceed an upper limit;
  * the surplus of animal manure, i.e. the manure that can not be used in the forage production systems, should not exceed an upper limit;
- socio-economics:
  * profit should exceed a lower limit;
  * labour used in forage and animal production systems should exceed a lower limit;
  * milk production should not exceed the quota allotted.

Apart from the goal restrictions the following constraints for integrated dairy farming have been identified:

- crops:
  * the total area cultivated with crops should not exceed the total available area;
  * the total area as allocated to the various production levels of each crop should not exceed the total area cultivated with that crop;
  * the supply of a crop with nutrients by applying chemical fertilizer and/or animal manure should at least be equal to the nutrient requirements of that crop;
- livestock:
  the forage produced should be divided over the various animal production systems in such a way that:
  * the amount of energy produced, if necessary supplemented with purchased energy in concentrates, is at least equal to the energy requirements of the cows;
  * the amount of nitrogen produced, if necessary supplemented with purchased nitrogen in concentrates, is at least equal to the nitrogen requirements of the cows;
  * the dry matter intake by the cows does not exceed the physiological limits;
  * the fraction of fibrous material in the diet is at least equal to the requirements of the cows.

Only when the optimization procedure is actually executed, it will become clear to what extent all those constraints can be satisfied, what are the most conflicting goals and to what extent they can be materialized. That has not been done yet. So far, the relations between the animal and plant production part and part of the inputs and outputs of the various production techniques have been quantified and the constraints are being formulated in mathematical terms.

CONTINUATION

The next step will be to apply IMGP to the dairy sector, as described before. Then for each of the goals defined in Table 1, a promising scenario should be selected. All goal restrictions in each scenario should in any case meet the lowest acceptable values. The scenarios should be defined in terms of inputs and outputs and be inserted in a national model. Such a model, which is probably suitable for this purpose, is developed under the auspices of the Netherlands Scientific Council for Government Policy. That national model is based on technical and not on behavioural relations, to be able to survey

long-term prospects of the Dutch economy and not to rule out breaks in the trend in advance (Netherlands Scientific Council for Government Policy, 1987).
After applying the second optimization with that extended model and a thorough analysis of the results, the scope for future development of dairy farming can be examined. The results do not indicate, however, the policy implications. An additional analysis is required to assess the policy measures needed to guide introduction or development of favourable production systems.

REFERENCES

Aarts, H.F.M., E.E. Biewinga, G. Bruin, B. Edel en H. Korevaar, 1988. Melkveehouderij en milieu (Dairy farming and environment). CABO-Report 79, CABO, Wageningen, 136 p.

Keulen, H. van and G.W.J. van de Ven, 1988. Application of interactive multiple goal linear programming techniques for analysis and planning of regional agricultural development: a case study for the Mariut region (Egypt). In: J.M. Broussard (ed.). Agriculture, socio-economic factors in land evaluation. Proceedings of a conference in Brussels, 7 to 9 October 1987, Commission of the European Communities, 36-57.

Meer, H.G. van der, 1985. Benutting van stikstof op weidebedrijven (Utilization of nitrogen on dairy farms). Landbouwkundig Tijdschrift 97 (8), 25-28.

Netherlands Scientific Council for Government Policy, 1987. Scope for growth. Threats to and opportunities for the Dutch economy over the next ten years. Summary of the twenty-nineth Report to the Government, Staatsuitgeverij, the Hague, 60 p.

Spronk, J. and F.R. Veeneklaas, 1982. A feasibility study of economic and environmental scenarios by means of interactive multiple goal programming. Regional Science and Urban Economy 13, 141-160.

Veeneklaas, in preparation. Dovetailing technical and economic analysis.

Weijden, W.J. van der, H. van der Wal, H.J. de Graaf, N.A. van Brussel and W.J. ter Keurs, 1984. Bouwstenen voor een geintegreerde landbouw (Building bricks for integrated agriculture). Preliminary and Background Study Series V44, WRR, Staatsuitgeverij, the Hague, 196 p.

Wit, C.T. de, H. van Keulen, N.G. Seligman and I. Spharim, 1988. Application of interactive multiple goal programming techniques for analysis and planning of regional agricultural development. Agricultural Systems 26, 211-230.