MODELING COMPLEX ECONOMIC-ECOLOGICAL INTERACTIONS IN THE AGRICULTURAL SECTOR IN THE NETHERLANDS

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ABSTRACT

In the Netherlands, ammonia emissions from agriculture contribute significantly to the acidification of soil and water. A 50-70 % reduction of these emissions within the next ten years is one of the great challenges for agricultural practice. This paper presents an outline of a combined system dynamics-optimization model of this problem, which will be used to study the effect of three different abatement scenarios.

A concise analysis of the acidification problem is given. The main causes of the current environmental problems of the agricultural system are described.

Next the choice of modeling techniques is discussed. System dynamics was applied because of the many (non-linear) interactions and delayed feedback relations in the agricultural system. The flexible responses to policy measures shown by the system's actors in the past, urged including economic optimization procedures in the model.

Some remarks are made on technical problems, using Professional DYNAMO linked with a FORTRAN optimization module.

The model contains an integrated description of the ecological problem in its economic context, with links to the related policy field of eutrophication. Interaction with reference groups consisting of experts and governmental officials, and interviews with representatives of interest groups have greatly contributed to the development of the model.

Only tentative conclusions can be presented at this stage, as results are still being worked on. However, a better understanding of the acidification problem has been reached, by the reference groups and the researchers. An interesting aspect is the link between emission reduction policy scenarios and possible shifts in land-related agricultural activities.

1. INTRODUCTION

The Netherlands has approximately 15 million inhabitants, living in an area of about 37.000 square kilometers (km^2). Agriculture is a minor sector of the economy, although it occupies 20.000 km^2. The major part of this area, 11.000 km^2, is used by dairy farming of about 2 million cows. Arable farming is practiced on about 5.400 km^2. Intensive livestock farming occupies only 2 % of the agricultural area, but accounts for large numbers of animals: some 14 million pigs and 93 million chickens in 1988.
In 1986, about 25 % of the total acid deposition on the Netherlands was due to ammonia emissions from the agricultural sector. These emissions account for about 200 thousand tons N yearly. NO_x and SO_2 contributed for 32% and 40%, respectively, to acid deposition. The main fraction of the ammonia deposition (75 %), stems from national sources. This is different from NO_x and SO_2 : only 35% and 20 % respectively % of these deposition come from national emissions. Therefore cutting down on national ammonia emission will diminish national acidification more directly than tackling NO_x and SO_2 emissions.

This environmental problem caused by agriculture has only recently gained a more general recognition. The farmers organizations, who at first denied and played down the problem, are now developing their own policies to tackle the problem. The need for at least 50-70 % reduction of ammonia emissions by the year 2000 is now generally agreed upon. New abatement techniques have started developing fast, but for some of these the effectiveness and costs are still uncertain. Several policy scenarios on abating ammonia emission haven been published and are still being developed. The policy debate concentrates on the question: "Which measures reducing ammonia-emission are the most cost-effective? "

In an attempt to provide insight in the possible effects of different policy scenarios, a model focusing on the problem of the emission of ammonia from manure was developed.
This effort was part of the SAL Project[1], which aims to investigate if and how interactive modeling techniques may contribute to the achievement of an integrated environmental-agricultural policy. During the first two and a half years a general model of the agro-ecosystem was constructed. With this model some exploratory studies have been carried out (Knol et al, 1987, 1989).
For the ammonia emission problem a new version of this model, disaggregated into crop production, dairy farming and intensive livestock production sectors and three different regions was developed.
The present paper describes the main aspects of this model. Special attention is given to the merging of system dynamics and optimization

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[1] SAL is a Dutch acronym meaning Systems Analysis of Agriculture. The project was started in 1986, by the Institute for Environment and Systems Analysis (IESA) in Amsterdam and the Department of General and Regional Agricultural Science (GRAS) of the Wageningen Agricultural University. It was funded by the University and the Ministry of Agriculture, Nature Management and Fisheries. The Agricultural Economics Research Institute LEI participates since 1989.

concepts into the model. No quantitative model results can be given yet, but the expected surplus value of a combined model will be discussed.

2. THE AGRICULTURAL SYSTEM IN THE NETHERLANDS: ANALYSIS OF THE AMMONIA EMISSION PROBLEM

In the past 25 years agriculture developed very successfully regarding its primary aim: food production increased substantially, at a decreasing input of labor while providing opportunity for industrial and general economic growth. The export of agricultural products, particularly to other European Community (EC) countries, increased and contributed to a surplus on the national balance of payments and to the increase in the level of the nation's prosperity. The agricultural sector seemed to develop favorably and steadily.

However, side-effects of agricultural activities appeared and have evoked criticism from a variety of interest groups. The major negative side-effects are:

- surplus production of e.g. milk and wheat, causing high charges for the EC-budget.
- surplus of manure, contributing to acidification, leaching of minerals, causing unacceptable nitrate concentrations in drinking water and bad smell.
- high energy input, usurpating natural resources.
- decreasing diversity in scenery and decline of the number of species of flora and fauna, caused by scale-enlargement.
- overload of the environment with pesticide residues, copper from animal feed and cadmium from fertilizer, which also threatens food quality.
- the deterioration of animal welfare (e.g. battery chickens, boxed calves).
- approaching loss of productivity, due to heavy metal residues, surplus of manure, soil compaction and increasing plant diseases caused by decreasing crop rotation.
- decline of output prices due to surplus production, resulting in low farmer income (particularly for small units) and hence decreasing employment opportunities for farmers and agricultural workers.
- increasing production costs due to environmental legislation.
- deterioration of working conditions on farms, e.g. long working hours, stress, and contamination when working with pesticides.

From this it may be clear that the agricultural system has to face several problems at the same time. Ammonia reduction measures may interfere with other measures, on local, national and European policy level, and may affect the dynamic state the system already is in.

Increase of Animal Production

What causes the high level of ammonia emission from agriculture? The main answer is the large number of cattle in a small country, as already mentioned. The cattle produce a huge amount of manure: some 100 million tons per year. Since 1970 the number of cows has increased by 10%, the number of pigs by 152 % and the number of poultry by 50 %. Of these sectors, dairy farming accounts for the highest ammonia emission: 57% or 140 Kton NH_3 yearly.

What caused the increase of production? The answer is a combination of exogenous technology development and a positive feedback-loop (fig 1; see also Budzik, 1975).
The positive feedback-loop connects livestock production, income and cattle stock. This loop was controlled by a continuous (but small) margin between production costs and selling prices.
The exogenous production technology development stimulated production while at the same time decreasing production cost per unit. The results of this process were a) scale enlargement and disappearing of small farms, and b) decreasing selling prices of all agricultural products, when inflation is accounted for. The latter is caused by the inelasticity of the demand for agricultural products. The large number of individual farmers made it impossible for them to control price level. Although agricultural policy protected fluctuation of selling prices to some extent, farmers still could only survive by constantly increasing production and improving efficiency.

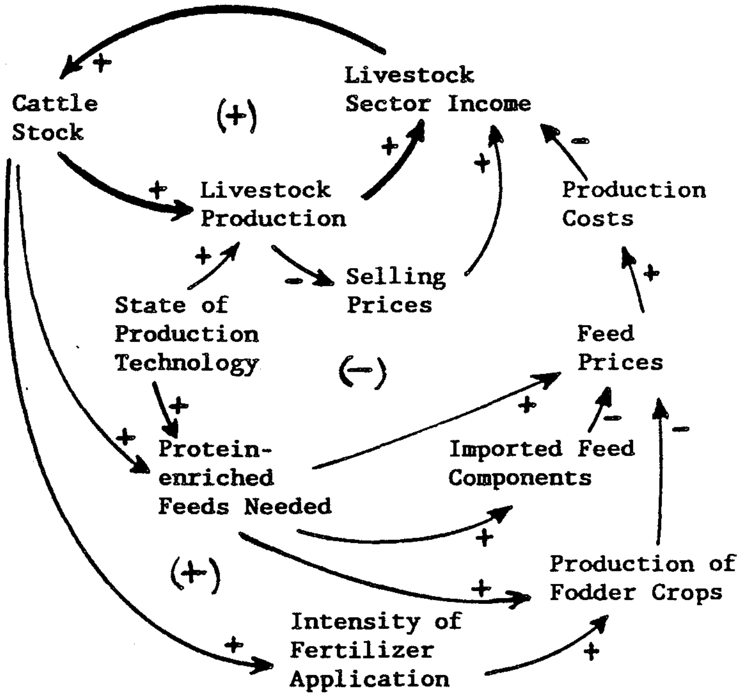

Figure 1. Increase of Animal Production.

Production technology required an increasing amount of protein-enriched feed per animal. This, together with the increasing cattle stock, led to an enormous demand for animal feeds. The application of fertilizer on meadows was intensified, and the acreage of fodder crops -mainly maize used for dry silage- rose from 64 km^2 in 1970 to about 1950 km^2 in 1988.
Still this couldn't meet the needs. Here a dormant negative feedback-loop of scarcity of feeds might have damped the increasing production, establishing a natural balance. Such a fragile balance is well known from the Sahel-example in system dynamics textbooks (e.g. Meadows & Robinson, 1985)

and is also illustrated in the contribution of Struif Bontkes to this conference. However, no fodder-scarcity occurred in the Dutch agro-ecosystem. Instead, large amounts of components for concentrated feeds were imported: mainly tapioca, maize gluten and soyameal expellers/extractions. These components could be supplied relatively cheaply because of the favorable location of the Rotterdam harbour. The industrial production of concentrated feeds doubled in the period from 1970 to 1988.

We will not elaborate here on other factors that stimulated animal production, like the supplier and food processing industries offering contracts and the creditbanks supplying cheap credits. We will also leave the market mechanism and the matter of production quota in dairy production, which are included in the model, for discussion elsewhere (see e.g. Knol et. al, 1987).

The Environmental Feedback-loop

Another dormant negative feedback-loop has recently come into action and now presents severe problems to agricultural development. It is shown in fig.2.

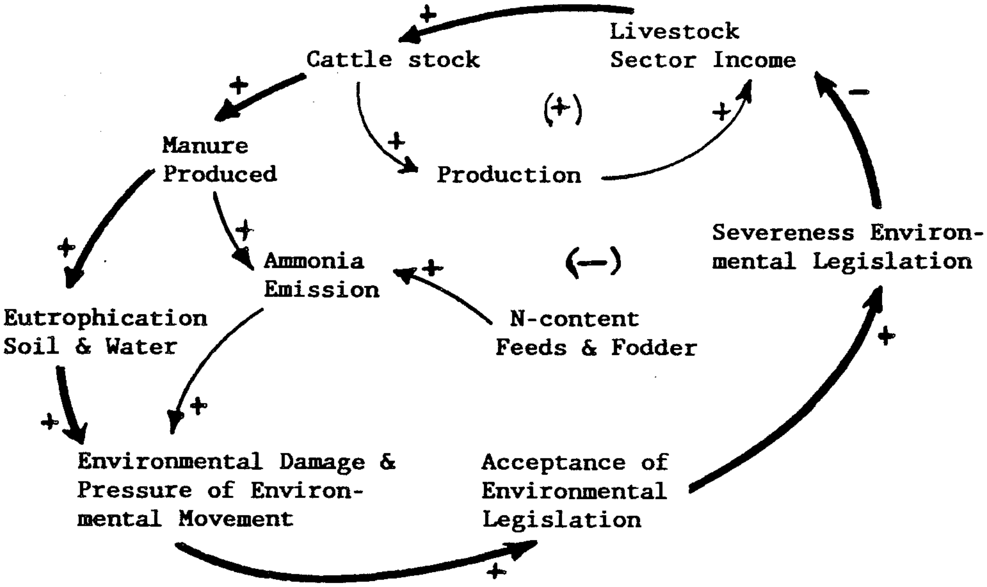

Figure 2. Delayed negative feedback-loop affecting agricultural production

Production increase raised the amount of manure. The large number of animals, the rising nitrogen content of the concentrated feeds and fodder - the latter due to intensive use of fertilizer- and a relatively low efficiency of protein uptake (cows: 15%, hogs 35%) resulted in large surpluses of ammonia, nitrate and phosphate from manure. The national nitrogen and phosphorus balances were disturbed. The negative environmental effects of this unbalance are ammonia emissions, contributing to acid deposition, eutrophication, phosphate-saturated soils and leaching of nitrate into groundwater and drinking water.

These effects have been foreseen and early warned for, but too little early listening occurred. Only after a substantial delay (15 years) more strict environmental legislation is now being established. The measures that are taken affect the agro-ecosystem in several ways but they all directly or indirectly limit the expanding production. It should be noted that dairy production expansion has stopped since 1984, due to the introduction of a quota system, which had an economic background. In 1986 the expansion of the pig and poultry farming sector was suddenly halted by legally imposed restraints. Before discussing the influences of various environmental measures, we will first take a look at the nitrogen flows in the system under consideration.

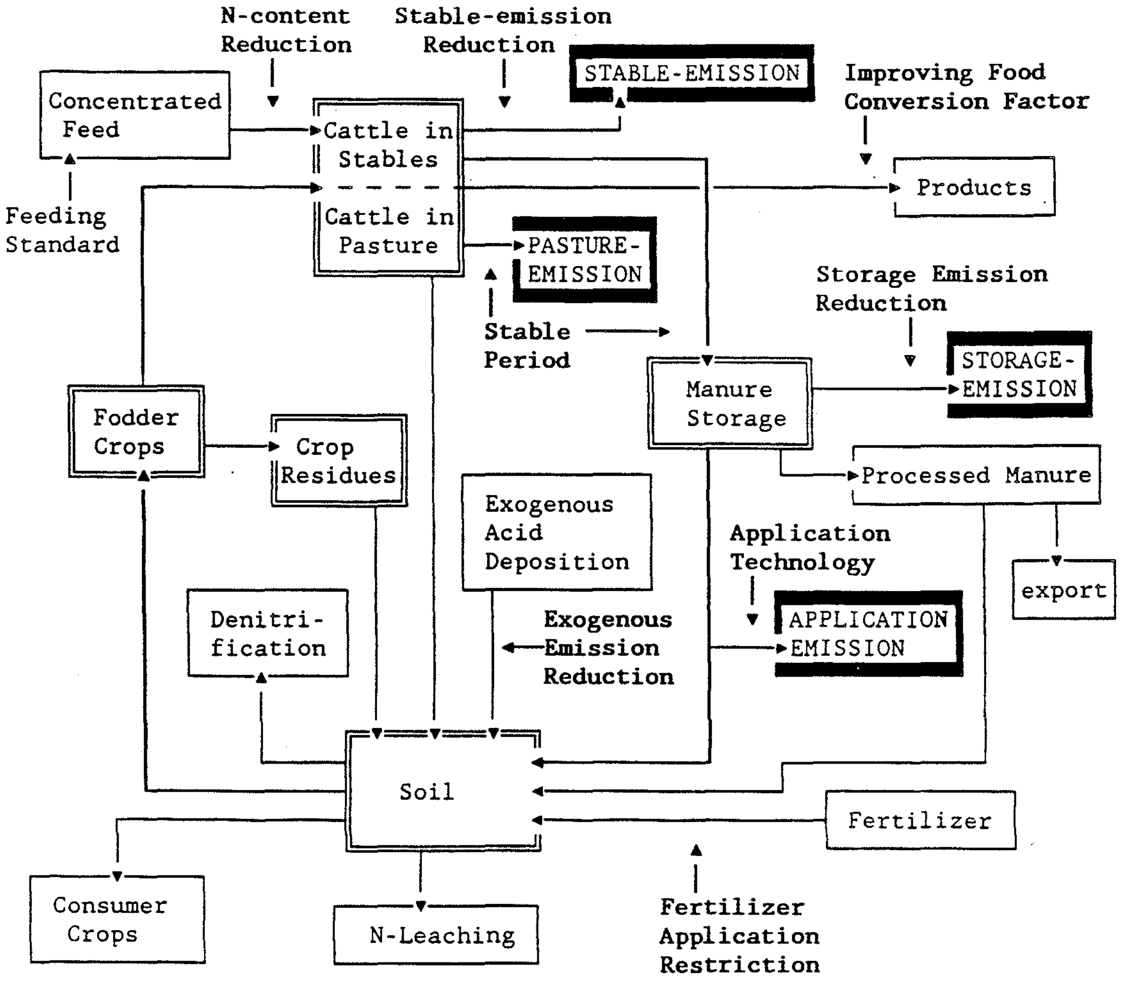

Fig.3. Nitrogen Cycle in the Agro-Ecosystem.
Single-lined boxes indicate inputs/outputs. Black boxes indicate different types of ammonia emission. In bold are measures that could reduce acidification (partly after Aarts et al. 1987). Not all measures are applicable to all animal categories.

Nitrogen Flow in the Agro-Ecosystem

Nitrogen is an essential and mobile element in the agro-ecosystem. The nitrogen cycle is not closed. The main exogenous nitrogen inputs to the system come from concentrated feed (in 1986: 454 million kg N), fertilizer (502 million kg N) and acid deposition (57 million kg N).
The output of agricultural products accounts for 216 million kg N, so some 80 % is lost: 187 million kg N escapes in the form of ammonia, 215 million kg denitrificates as N_2 or N_2O and some 215 million kg leaches eventually as nitrate into the groundwater (Olsthoorn, 1989).

Fig. 3 shows a simplified nitrogen cycle of the agro-ecosystem. Special attention is given to the various types of ammonia-emission (in black boxes). Their relative contribution to the national ammonia emission is as follows: 37% escapes from stables, 10% from pastures, less than 1 % from storages and 52% from application of manure on the land. These types of emissions can be tackled by various measures. In figure 4 the continued effects of several measures on the system are shown in a causal diagram.

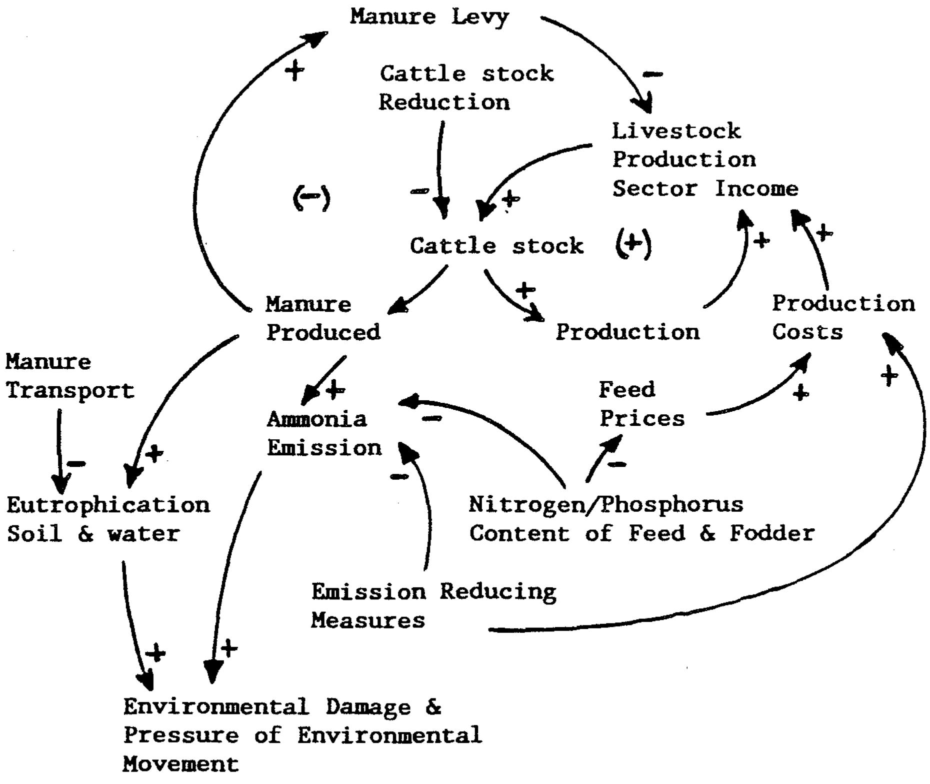

Fig. 4. Action of some Ammonia Abatement Measures

Both figure 3 and 4 make clear that an improvement in one stage sometimes only shifts the problem to another part of the system:

- Storage emission can be reduced by covering manure-silos, but then more ammonia is kept in. This may then escape when spreading the manure over the land.
- A longer stable period reduces pasture-emission (but enlarges stable-emission, and may affect animal well-being negatively)
- Reducing stable-emission by bio-filtering ammonia from the air in stables, results in wastes that require processing (and is very expensive)
- One of the techniques for application of manure, that is being developed at present is injection of manure into the soil. Unless application rate is adjusted, more N will flow as nitrate into the soil and will leach into the groundwater. The measure is also more expensive than the traditional spreading of manure over fields.
- Transport of manure to regions where no surplus of manure exists. Because regulations limiting the amount of manure brought on the soil will become more strict in near future, these regions will become scarcer and transport distances will grow longer.

More fundamental solutions, though not advocated by all interest groups are:

- Lowering N- (and P-)content of concentrated feed (15% is feasible, more becomes too expensive)
- Lowering the N-content of fodder, by cutting back the use of fertilizer and producing other fodder crops.
- Processing manure to pellets, that are equivalent to fertilizer, and may be exported. Still being developed and costs still uncertain.
- Reducing cattle stock, either by direct legal restrictions or by financial incentives.

Most measures will not affect the cattle stock directly, but will enforce the survival of the fittest: small or inefficient farms will disappear. However, the production capacity may be taken over by larger farms, so it's uncertain what effect this struggle will have. There are more uncertainties. Farmers are clever entrepreneurs. They are able to optimize their actions into a direction that government officials do not foresee.

3. CHOICE OF MODELING TECHNIQUES

Model requirements

The analysis given above prompts for some conclusions on model requirements. First we may notice complex relationships between many elements of the agricultural problems. The main criteria that have to be fulfilled are reasonable farmer income and agricultural employment, minimal levels of ammonia emission and eutrophication, and sufficient economic development without excessive government funding.

Second, we may conclude that the system is in a very dynamic state. The cost/benefit ratios of various types of agricultural production (livestock as well as crops) are rapidly changing. Environmental policy measures to be take soon may enforce these dynamics. So a dynamic model is desirable.

Third, we see that financial parameters play an essential role. The success or failure of any measure is determined by costs per unit of product. So a very precisely tuned set of parameters is needed.

Fourth, we have to take into consideration the great flexibility to adapt to new situations that farmers have shown in the past and are likely to maintain.

System Dynamics and Optimization

These demands brought us to a mix of system dynamics and optimization in one model. Although a mixed model may overcome the limitations that each technique separately has, it often evokes a paradigm conflict. Meadows & Robinson (1985, p.75) compare the process of completely merging econometrics and system dynamics to the competitive exclusion process in an ecosystem: only in different niches can both coexist, otherwise one of the two paradigms must dominate the other. The best that is possible, they state, is a composite model in which one paradigm lends a few useful elements from the other's toolkit. An example is the approach of De Wit et al. (1988), in which a simulation model produced input for a LP model. Although we sympathize with the view of Meadows & Robinson, we will try to challenge this conflicting situation. Recently more attempts for integrated models have been made. Bruckmann and Fleischner (1989) constructed a econometric/system dynamic model of the Austrian economy. Radzicki (in press) pleads for combining institutional economics and system dynamics.

Optimism/pessimism

An interesting element in the debate on optimization modeling versus system dynamics is the tendency, or bias, that each technique may have in its results. System dynamic models with many feedback-loops have a name to produce results which are too pessimistic, while optimization methods may be too optimistic on the result that could be reached. This can be understood from the nature of each method.

System dynamics model behavior is mainly determined by the **action-reaction patterns** that are incorporated in it. New reaction patterns that have not been foreseen may occur, when a dormant loop becomes active. However, it is unrealistic to expect that all possible reactions to new phenomena may be present in a limited model structure.

In the case of optimization only the **known constraints** on human acting are included in the model structure. The question still is, if the calculated optimum can really be reached in practice, because there may be constraints on human acting than could be foreseen.

We expect that including some elements of the optimizing strategy of farmers in the system dynamics model may correct the pessimistic bias to some extent. We will show in section 5 how bias in the outcome of the optimization is corrected.

Reference groups

The model was developed in interaction with reference groups (according to Randers, 1977) consisting of government officials from the Ministry of Agriculture, Nature Management and Fisheries. These groups were closely involved in the refinement process and discussed the current policy scenarios that were to be used.

Technical Realization

The production-ecology and policy submodels haven been programmed in Professional DYNAMO plus version 3.1c. Together they contain about 800 levels, 1000 rates and 2000 auxiliaries.

The economic submodel has been programmed in Microsoft-Fortran 5.0, and takes about 2500 lines, plus an external LP-routine of about the same size.

The link between these two is accomplished by the external function facility of DYNAMO.

The Dynamo model is first compiled to C-code, which in its turn is compiled with Microsoft C 5.1. The C-program turned out to be too large for compilation in one step, so the DYNAMO-generated C-code had to be broken up in parts, that are compiled separately and then linked. To link the FORTRAN subroutine to the main model the C-code generated must be edited by hand. The external function identifier is moved to a separated declaration statement containing the FORTRAN keyword. However, the generation process is time-consuming, with models as large as we used.

4. STRUCTURE OF THE MODEL

The model focuses on the problems in livestock production. However, crop production has been added because of the strong interaction between the two. Criterion variables on the performance of the crop production sector are not included. All possible crops have been aggregated into three categories: fodder maize, grass and 'arable crops'.

In livestock we distinguish the categories dairy cattle, 'other grazing animals', pigs, and poultry. All these agricultural activities may be practiced to any extent in three regions, aggregated as the sand, clay and peat areas.

The model is subdivided into an economic, a production-ecology, and a policy submodel. The economic submodel calculates the optimal mix of activities per region on an annual basis, given the profits/losses of the activities in previous years and under constraints imposed by policy measures.

The data of the activities chosen are then transferred to the production-ecology submodel, that simulates the environmental side-effects. These side-effects have their costs, which are fed back into the optimization of activities next year. In both models estimated parameters from econometric calculations are used whenever possible.

The third submodel contains blocks of policy measures and mainly provides input to both other submodels. For instance, compulsory ammonia emission reduction in the pig production sector will both decrease ammonia emission and raise production costs. As a result, farmers may decide to abandon pigs and shift to another production sector in the next years.

The Production-ecology Submodel

This submodel is basically a nitrogen flow model, as depicted in fig. 3, and developed according to system dynamic conventions. It describes the following processes (in each of the three regions mentioned):

- Inputs of nitrogen into the system, originating from concentrated feeds, fertilizer and acid deposition,
- Uptake of nitrogen by crops from the stock in the soil, which is supplemented by fertilizer and manure during the growing season,
- Nitrogen flow in the production processes of 4 livestock categories, Important factors are the feed conversion and the surplus of nitrogen present in feed and fodder,
- Production of manure by all 4 animal categories,
- The accumulation process of N in biological material,
- N-losses by denitrification and leaching,
- Feedback of crop residues to the soil,
- Ammonia emission at different stages of the production process,

- The effects of ammonia reduction measures at different places in the system,
- The costs that these reduction measures entail.

The Economic Submodel

This submodel describes short-term as well as long-term supply response in the agricultural sector. The profits/losses of the possible activities are the main determinants. Short-term reactions concern optimal exploitation of present means of production, like stables and land. In the long run measures like (dis)investments, dismissal of labor and technological progress may result in major shifts.

Model specification is mainly derived from ECAM, the European Community Agricultural Model (see Folmer e.a., 1989). A simplified representation is given in fig. 5.

A non-linear optimization determines optimal cattle stocks and crop acreages for all regions. As discussed in the previous section, optimizations tend to be too optimistic. In this particular case, switching and adaptation to new activities takes much more time, investments and new skills. To reflect this, substitution elasticities have been estimated from historical data. These are introduced as extra constraints into the optimization.

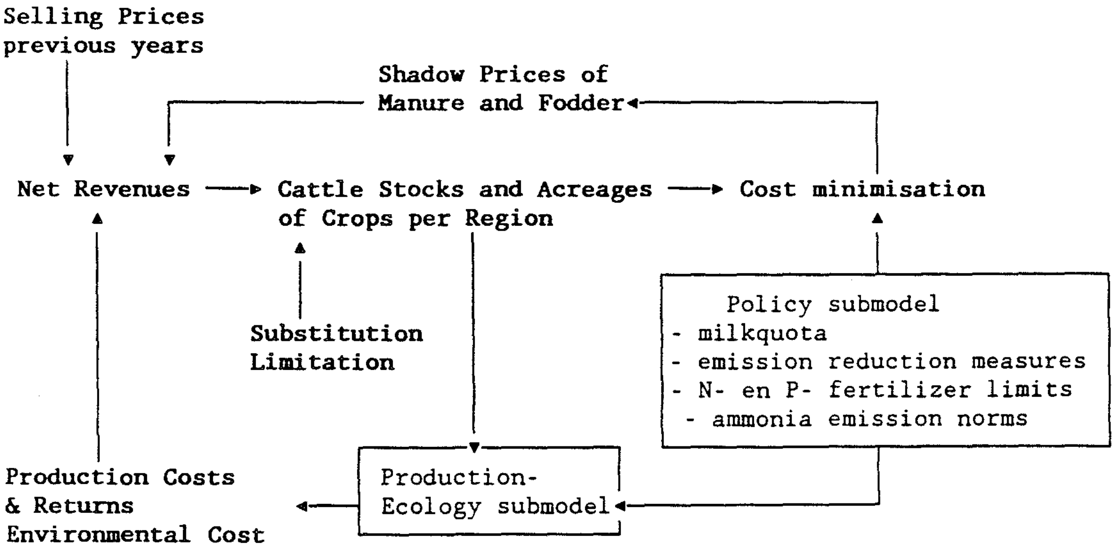

Figure 5. Outline of the Structure of the Economic Submodel.

For livestock production a net revenue maximization, subject to constraints from policy measures, is included in the model. In the yield function a technological trend (higher yielding varieties) is accounted for. Besides market prices of fertilizer, pesticides and concentrated feeds, prices of manure and fodder are needed as inputs. These prices are not known, because there is hardly any trade of these products. Therefore, shadow prices for these products are first calculated from a cost minimization. Given the

calculated cattle stocks, a feeding standard which must be met, and an amount of available fodder (fresh and from silage), it is calculated how much concentrated feed will have to be supplied. By feeding back these values into the optimization, an optimum is calculated by iteration.
The cattle stocks and crop acreages thus calculated, are transferred to the production-ecology submodel. This, in turn, generates input for the economic submodel's next year cycle.

5. SCENARIOS

Three different sets of policy measures, combined into scenarios, have been prepared for testing with the model. Each scenario was based on a policy document of one of three interest groups: the farmers organizations, the environmental movement and the government. A summary of these scenarios is given in table 1.
It will be clear that the differences in the scenarios are small. The interest groups have converged to a considerable extent. An important issue remains the necessity of forced cattle stock reduction. Also, confidence in the technology for processing manure to present a reasonably cheap solution, differs. A compulsory supply to manure processing plants is being considered, as well as a levy on all manure produced. The funds resulting from this levy may be applied to make manure processing cheaper. Regarding modifications made to stables to reduce ammonia emissions, the farmers organizations will only accept these for those types of stables where they are relatively cheap. The other groups advocate a system of emission maxima for all cases, which will force the farmers to modify their stables or reduce their cattle stock.

Table 1 **Objectives for ammonia reduction and proposed measures for three scenarios**

Scenario	Farmers Organizations	Government	Environmental Movement
NH_3 reduction in 2000	50%	65%	80%
NH_3 reduction in 2010	70%	85%	90%
Mineral Reduction in feeds	15%	15%	25%
Emission Reduction at application of manure	50%	80%	80%
Stable modifications	Limited	By Emission Limits	By Emission Limits
Capacity for Processing Manure ($*10^6$ tons)	20	20	4
Cattle Stock Reduction	No	No	Yes

6. DISCUSSION AND CONCLUSIONS

When the above was written, no quantitative results were available. The outcome of the three different scenarios is expected to evoke an interesting debate in the reference groups and probably elsewhere. Contacts made with interest groups, to check our translation of their policy documents into policy scenarios, confirm this. A meeting has been scheduled where representatives of different groups will discuss the results.

However, quantitative results are only part of the aims of the SAL project. A major surplus value is in the combination of economic, production- and environmental aspects that is covered:

- the linking of the acidification problem, and measures to abate this, to possible shifts in agricultural production,
- the interference of different abatement measures,
- the relations between input of minerals to the agro-ecosystem, manure produced and ammonia emission,

This, together with the long term scope of the study, has proven to be interesting and new.

Another important question is if people involved in the project have gained a better understanding of the functioning of the agro-ecosystem. We have found that it was possible to illustrate effects of policy measures on different parts of the system. Discussions in the reference groups, and in the earlier stage of the project, in workshops, were revealing different views. Further, we have reached an interesting mix of economic and system dynamic modeling techniques. We hope this "enriched methodology" may contribute to better models in the crossing of both fields.

REFERENCES

Aarts, H.F.M., E.E. Biewinga, G. Bruin, B. Edel and H. Korevaar, 1988
Melkveehouderij en milieu. Een aanpak voor het beperken van mineralenverliezen. (Dairy Farming and Environment. An approach to deminishing Mineral Losses) PR report nr 11, Lelystad, The Netherlands

Budzik, P.M., 1975
The Future of Vermont Dairy Farming: a Dynamic Policy Model For 1962-2002.
2 vols., Report nr. 45, Darthmouth System dynamics Group, Darthmouth College, Hannover, N.H.

Bruckmann, G. & P. Fleissner, 1989.
Am Steuerrad de Wirtschaft. Ein ökonomisch-kybernetisches Modell für Österreich. Springer Verlag, Wien, 209 p.

Folmer, C., M.A. Keijzer, M.D. Merbis, H.M.E. Schweren & P.J.J. Veenendaal, 1989.
Modeling Alternative Common Agricultural Policies. in: W. Henrichmeyer (ed): Agricultural Sector Modeling. Vauh, Kiel.

Knol, O.M., G.O. Nijland, F.C.M. Verberne & K. Wieringa, 1987
Development of a General System dynamics Model of the Stability Problems of the Agro-Ecosystem in the Netherlands. Paper presented at the Congress Environmental Policy in a Market Economy, september 1987.

Knol, O.M., J.S.O. van Asseldonk & G.O. Nijland, 1988
Randvoorwaarden stellen aan de landbouw. ('Boundary Conditions to Agriculture') in : Verslag symposium Boer, Bodem en Beleid, Vakgroep Ruimtelijke Economie, VU Amsterdam, 21 april 1988.

Knol, O.M., G.O. Nijland & M.W.L. Bovy, 1989.
Development of a General System Dynamics Model of the Stability Problems of the Agro-ecosystem in the Netherlands. Draft version distributed at the 1989 SD Congress, Stuttgart.

Meadows, D.H. & J.M. Robinson, 1985
The Electronic Oracle, Computer Models and Social Decisions J. Wiley & Sons, Chichester etc. 445p,

Olsthoorn, 1989.
Stikstof in de landbouw: waarheen? (Nitrogen in Agriculture, where does it go?) Landbouwkundig Tijdschrift, Vol 101, no 12 22-26

Radzicki, M. J.(in press)
Methodologia Oeconomia et Systematis Dynamis. System Dynamics Review, forthcoming

Randers, J.,1977.
The potential of simulation in macro-social processes, or: how to be a useful builder of simulation models. Gruppen for Resursstudien, Oslo.

Struif Bontkes, Tj, 1990
Simulation as a tool for planning of rural development programmes, A case in Southern Sudan, Proceedings 1990 SD Conference, Boston.

Wit., C.T. de, H. van Keulen, N.G. Seligman, & Ispharim, 1988
Application of Interactive Multiple Goal Programming Techniques for Analysis and Planning of Regional Agricultural Development. Agricultural Systems, 26 211-230.