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The Survey of the Agroeconomical Potential of Hungary - A Brief Summary

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THE SURVEY OF THE AGROECOLOGICAL POTENTIAL OF HUNGARY - A BRIEF SUMMARY

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PREFACE

This paper deals with two subjects: first we give a short account of "The Survey of the Agroecological Potential of Hungary" and then we outline a model for regional allocation of agricultural investment. The latter model is going to be a component of a model system developed for the methodology for the Hungarian Task 2 Case Study of the "Analysis of the Impacts of Technological Development on Production and the Environment".

The first subject is not connected with IIASA research but the results of the ecological survey project can serve as a data basis for the planned case study now under way. The first chapter contains, besides the description of the data basis, a short summary of the main goals of the study and also of its methodology.

In the second chapter we give the concept of the investment submodel of the planned model system of the Hungarian Task 2 case study.

This paper was prepared by Z. Harnos, Head of Department, Bureau for Systems Analysis (Budapest) during his visits to the International Institute for Applied Systems Analysis (Food and Agriculture Program) in December 1980.

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THE SURVEY OF THE AGROECOLOGICAL POTENTIAL OF HUNGARY - A BRIEF SUMMARY

Zsolt Harnos

The basic goals of the project were to determine the maximal amount of production that, given the natural environment, meteorological effects, soil properties, water supply, the genetic properties of plants, and the partial modification of environmental factors (amelioration, irrigation), can be obtained around the turn of the century. The agroecological potential was calculated based on the hypothesis that it is basically the presently known advanced procedures that will be used to produce the primary food materials in 20 to 22 years' time. No fundamental or completely new results in plant breeding, fertilizer, water techniques or usage which could put plant production on a completely new basis were taken into consideration.

Any major unexpected or unpredictable scientific achievement will only improve the examined situation. The procedure used for the survey is shown in Figure 1.

The prognosis of yields was carried out for every branch of cultivation, but here we will deal only with the production of field crops, because this plays a fundamental role in the planned work: the analysis of the impacts of technological development on production and the environment.

The ecological factors taken into consideration for the yield prognosis are as follows:

(a) characteristics of natural geography

(b) meteorological conditions

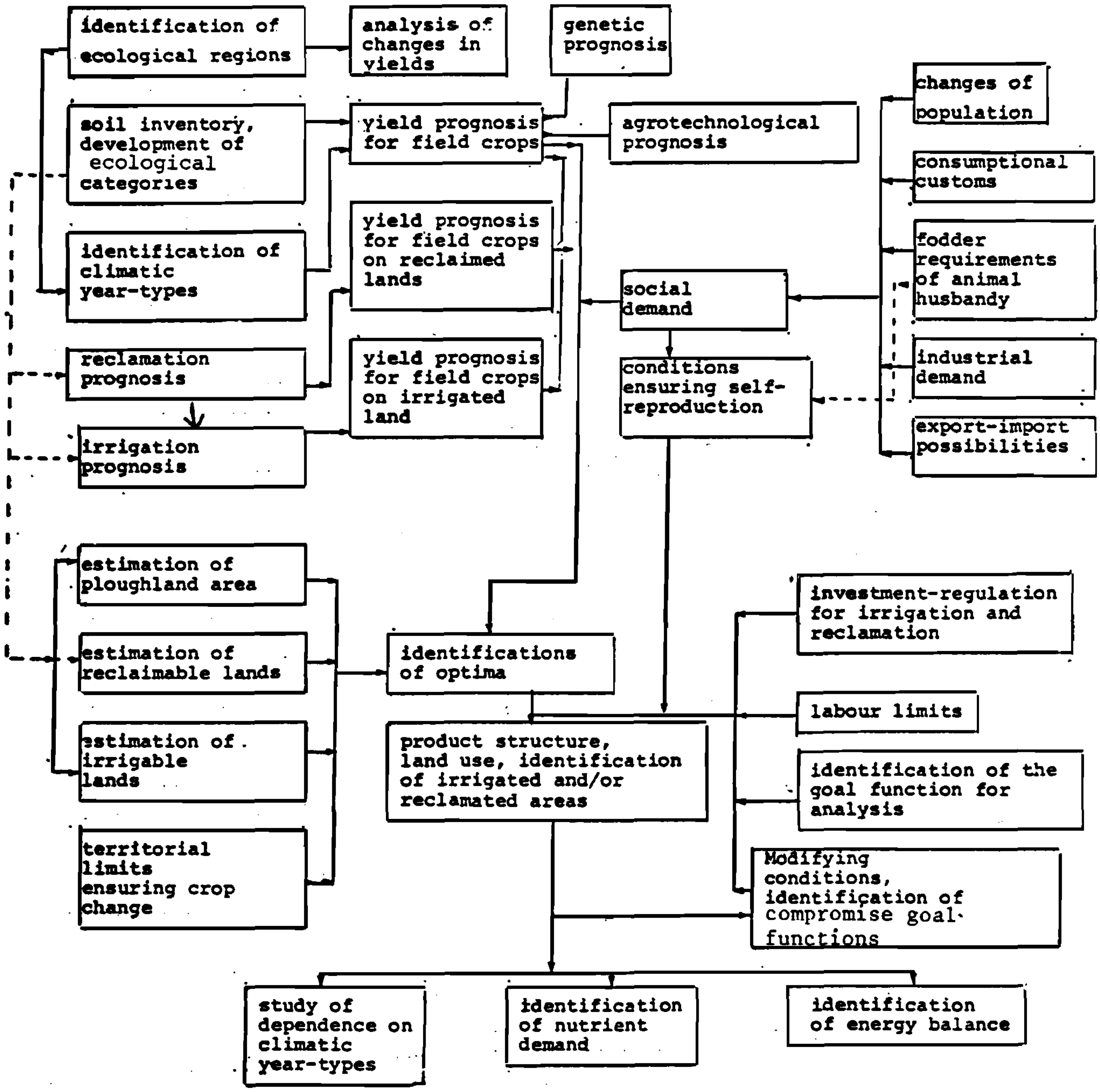

Figure 1. Structure of the Model Describing the Allocation of Field Crops and Vegetables.

(c) soil properties

(d) hydrological conditions

(e) genetics

At the first stage 35 agroecological regions were determined according to natural and economic geography. Meteorological conditions were considered as homogeneous within these regions, and they were described using a large number of meteorological parameters. Data were collected over a period of 25 years for each agroecological region.

The most important field crops were then selected. The 13 crops considered separately in the model are as follows: wheat, maize, winter and spring barley, rice, rye, alfalfa, red clover, sugar beet, potato, soybeans, sunflower and fodder peas.

Production data of these crops for the 25 year period were also collected. Factor analysis and some non formalized procedures were used in the selection of the characteristic meteorological parameters. Using production and meteorological data we determined climatic year types for each region. The concept of climatic year types enabled us to account for the variability of weather in time in a relatively simple way. Individual year types are usually characterized by parameters relating to precipitation and temperature in certain parts of the vegetation period and by their probability of occurence.

Climatic year types were obtained by the use of Ward's cluster analysis. Ward's procedure is an iterative process, with each iteration consisting of two norm minimization problems. At the start, each individual constitutes a separate cluster:

$$\underline{c}_1^{(k)}, \dots, \underline{c}_{25}^{(k)}.$$

$\underline{c}_i^{(k)}$ stands for the vector of climatic parameters of the k-th region, now being the center of the i-th cluster. Each iteration decreases the number of clusters by one in the following way. The solution to the problem

$$\min_{ij} \frac{m_i \cdot m_j}{m_i + m_j} || \underline{x}_i - \underline{x}_j ||$$

is determined, where $\underline{x}_i$ is the center of the i-th cluster and m_i is the number of the points it contains. The resulting two "nearest" clusters are united. The center of the new cluster is given by the solution of the problem

$$\min_{x \in R^p} \sum_{i=1}^{m} || y_i - x || ,$$

with $\underline{y}_i, i = 1,2, \cdots m$ being the i-th point of the newly created cluster, and p is the number of the climatic parameters considered.

Ecological regions were further divided into soil mosaics according to the quality of the habitat, which we characterized by soil and hydrological conditions. We considered 31 different soil types, and this resulted in a number of soil mosaics surpassing 200.

A special study was prepared on the expected development of the genetic potential of the main crops. The yield prognosis is based on this study, and it gives the expected yield of all the 13 main crops for each soil mosaic and climatic year type. Using the probability of the year types, the expectation value of the yields with respect to weather was also determined. In the sequel, we used mainly these values.

A collective feedback expert inquiry combined with a mathematical statistical analysis was used in the prognosis.

A forecast based on the methods of econometrics was also constructed to check the experts' prognosis. In this, the development of yields was considered to be a saturation process, or otherwise, we supposed that the development of yields is determined until the turn of the century by factors already present, and the increase of yields is due to the ever increasing utilization of inherent possibilities.

The supposed distribution function of the saturation process is shown in Figure 2.

This means that, we supposed that the development of the yields between 1900 and 2000 is described by a symmetric logistic function, its graph and analytic form is shown in Figure 3, with the parameters meaning:

t - the time in years, $t \in (1900, 2000)$

p_1 - the initial level of yield (the assymptotic yield level) before the considered period

p_2 - the level to be achieved at the end of the period considered

p_3 - the constant proportional to the rate of fastest growth

p_4 - the time of fastest growth

The development curves for the yield of wheat is shown in Figure 4. In three cases, the value of p_2 was fixed according to the results of the experts' inquiry (the three levels correspond to the pessimistic, moderate and optimistic opinions). This means the acceptance of these values being valid between 2000 and 2010. In the case of the fourth, there were no such constraints.

Environmental conditions of the soil mosaics can be improved by amelioration and irrigation. In the second phase of the prognosis, experts assessed the location and kind of necessary meliorative treatments, and the effect of these investments on the forecasted yields. The same work was also carried out on irrigation.

Thus we obtained a complete prognosis, which included the yield prognosis on the original, ameliorated and irrigated soil mosaics, respectively. Such a detailed prognosis makes it possible to determine optimal land use patterns.

The main goals of the computations were:

- the analysis of the relationships between land use pattern complying with natural conditions on one hand, and the required total production (social demand), on the other;

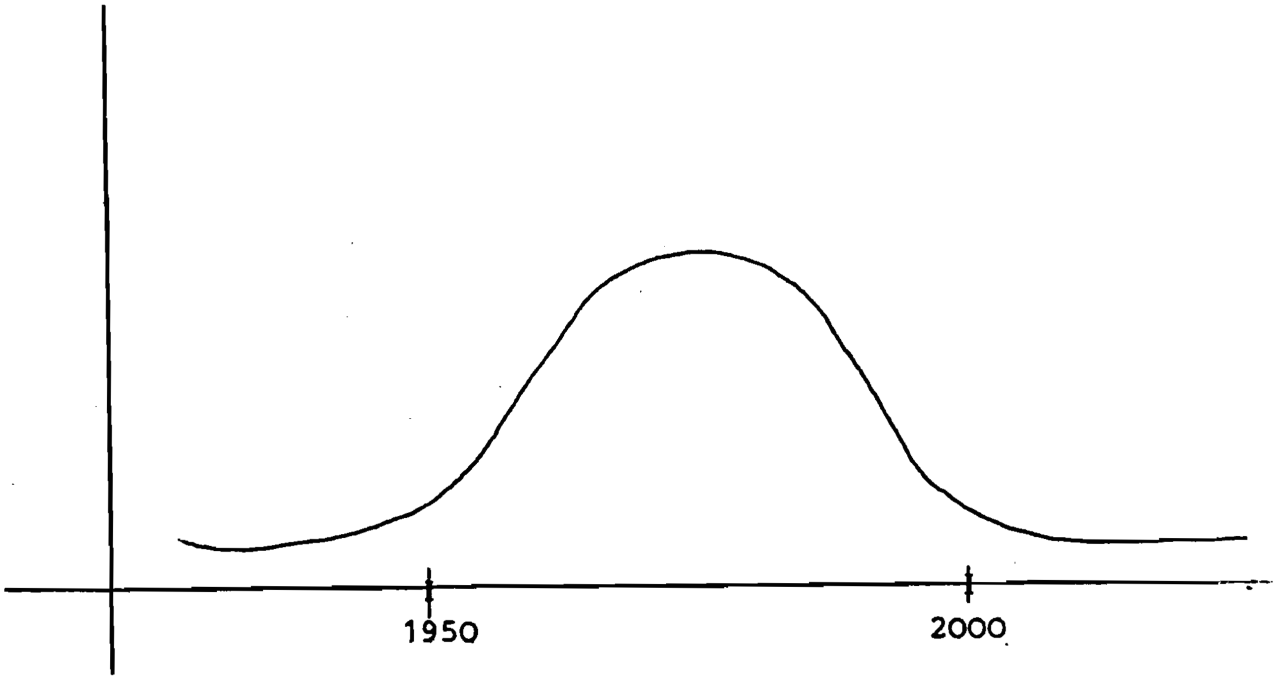

Figure 2. Velocity of acceptance.

$$f\left(t;\ p_1, p_2, p_3, p_4\right) = p_1 + \frac{p_2 - p_1}{1 + e^{-p_3 \left| t - p_4 \right|}}$$

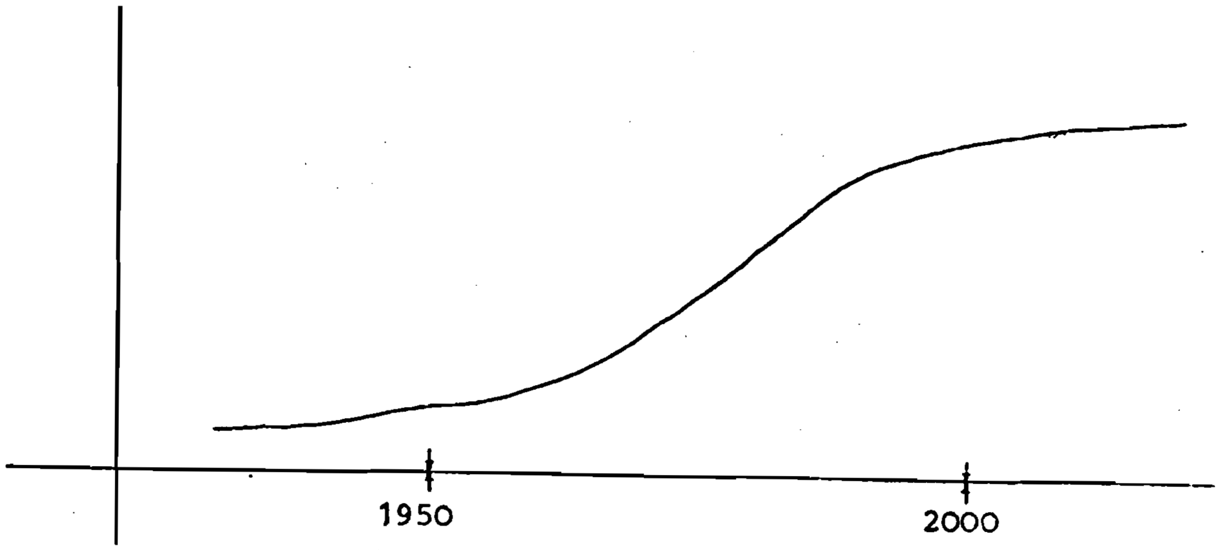

Figure 3.

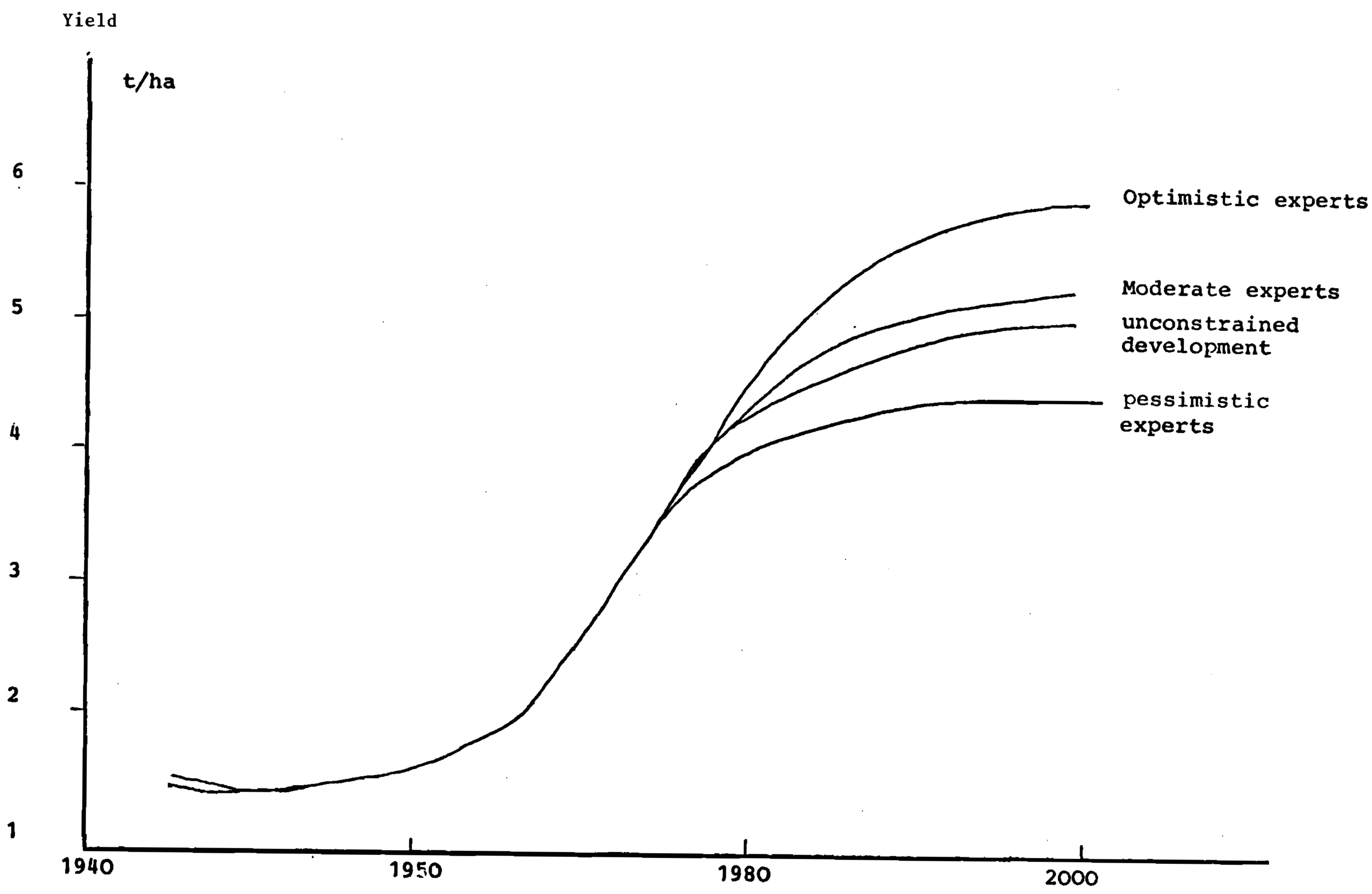

Figure 4. National average of the yield of wheat.

- the analysis of the dependence of land use patterns and total production on the amount of investments into land reclamation and irrigation and on their realization in time.

To solve this problem, we used a two level hierarchical model. The first, so-called regional model describes the problem in an aggregated form. In this case the regions constituted the land units. The social demand (with respect to the production structure), land reclamation investment conditions and others are formulated in this model.

Results give a regional allocation of investments and land use. A global analysis of the crop production system and that of the interdependence of land use and product structure can be carried out by using this model.

The second model served for a detailed analysis. This consisted, in fact, of four separate models. The country was divided into four large regions, and the crop production activity was described by separate models in each of them. Their structure is similar to that of the regional model, but the constraints (like the product structure, the allocation of land reclamation investments and goals) were formulated on the basis of the results of the regional model.

The regional model is described by a system of linear inequalities parametrized on the right hand side.

$$\underline{\underline{A}}\,\underline{x} \le \underline{b}_o + \lambda\,(\underline{b}_1 - \underline{b}_o) \qquad (1)$$

$$\underline{x} \ge \underline{0}$$

$$\lambda \in [0,1]$$

Let us denote the set of the solutions of the above system by Ω . Our task is to determine an $\underline{x}^* \in \Omega$, with all the goal functions

$$\varphi_i(\underline{x}) = \langle \underline{c}_i\,,\,\underline{x} \rangle \qquad i \in I = \{1,2, \cdots ,l\}$$

reaching their optima, that is

$$\varphi_i(\underline{x}^*) = \max_{\underline{x} \in \Omega} \varphi_i(\underline{x}) \qquad i \in I$$

This optimization problem , however, has no solution in general , and for this reason we have to find the set of Pareto-optimal points or at least some of them, that is some of the $\underline{z}^* \in \Omega$ with

$$\underline{\varphi}(\underline{z}^*) = \text{P--max}\,\{\underline{y} : \underline{y} = \varphi(\underline{x}), \underline{x} \in \Omega\}$$

The maximum here is taken over R^l with respect to the ordering induced by the natural positive cone R^l_+. That is to say:

$$\{\varphi(x); \underline{x} \in \Omega\} \cap \{\underline{\varphi}(z^*) + R^l_+\} = \{\underline{\varphi}(\underline{z}^*)\}$$

Two, so-called compromise solutions were determined from the set of Pareto- optimal points.

At the first step the utopia point in R^l was determined for the problem (1). As a consequence of the definition of the utopia point, its i-th coordinate satisfies $\beta_i = \varphi_i(\underline{x}^{(i)})$, where $\underline{x}^{(i)}$ is the solution of the problem:

$$\underline{\underline{A}}\,\underline{x} \le \underline{b}_0 + \lambda\,(\underline{b}_1 - \underline{b}_0)$$

$$\underline{x} \ge \underline{0} \quad \lambda \in [0,1]$$

$$\varphi_i\ (\underline{x}) \to \max$$

Then we constructed two new goal functions by using the utopia point,

$$\Psi_1\ (\underline{x}) = \sum_{i=1}^{l} \left[1 - \frac{<\underline{c}_i\,,\underline{x}>}{\beta_i}\right]$$

and

$$\Psi_2\ (\underline{x}) = \max_{1 \le i \le l}\ (\beta_i - <\underline{c}_i, \underline{x}>),$$

respectively and then we minimized them on the set Ω.

These solutions are Pareto-optimal points of the system. The solutions of the regional model produced land use patterns on a regional level. We used these solutions to determine the production structure and the extent of land reclamation and irrigation.

Taking the results as constraints and taking their corresponding goal functions, the linear programming problem describing the crop production of the four large regions was solved.

Let us now turn to the description of the main relationships and to the explanation of our choice of methodology.

The constraints can be grouped as follows:

- area constraints,
- constraints of the product structure,
- crop rotation conditions ensuring the continuity of production,
- constraints regulating the extent of land reclamation and irrigation investments.

Cropland was considered to be homogeneous in the regional model, with three kinds of possible activity:

- production corresponding to the present situation
- production corresponding to the situation after land reclamation (amelioration);
- production on reclaimed and irrigated land.

The area of irrigable and reclaimed land was limited in each region. The total area cultivated in the three possible ways had to be equal to the total cropland in the region. The total available cropland in the regions was changed according to the amount of land under nonagricultural use.

The demand that crop production had to meet consisted of two parts:

-- home consumption, and the demand of agriculture ensuring the continuity of production and reproduction;

-- exports, imports.

The third group of constraints is for the control of the territorial structure of the production. It is the territorial constraints determined for each region that ensure the realizability of the crop rotation plan. These are of two kinds:

- those given in the form of a limit for the ratio between the area occupied by certain (groups of) crops;
- those limiting the area occupied by certain (groups of) crops from above or below.

Similar conditions were formulated for irrigated or reclaimed land and for the ratio between irrigated and dry cultivation. All the above mentioned parameters were expressed in natural units and the same is true for the constraints. There was, in fact, one single condition of a nonecological character, and this was the extent of land reclamation investments.

Reclamation is a significant means for increasing the yields, but we cannot expect all the reclamation work to be finished in the near future.

In the course of our investigations, more than 20 different forms of land reclamation were considered, with different investment requirements. The rise of yield due to land reclamation being already known from the prognosis, investment costs in current prices were sufficient to determine the optimal allocation and time order of land reclamation projects. The volume of material investment was limited. The solutions under the different investment constraints gave the opportunity to determine the expedient location and time order of land reclamation projects.

The structure of the outlined model can be seen in Figure 5. Some of the lower bounds are equal to zero while some of the upper bounds may be infinite, meaning that there is no limitation. The system of inequalities means a series of problems of an ever growing size but of constant structure. The matrices A_t and A_y were the same in all cases while in the matrices A_k , relationships controlling the land use pattern were gradually extended. The solutions in the less constrained cases showed great differences between the production areas of the individual crops. By the gradual extension of the conditions, however, the land use pattern reached a stable form, that is from a certain step onwards, the different goals did not make the land use pattern change significantly.

The description of the parameters serving as a basis of the production and of the main forms of the factors influencing production is herewith finished.

The possible land use patterns are represented by the solutions of system (1). The main problem here is to choose the criterion of optimality.

The usual goals in economic planning - like the maximization of net income, the minimization of costs - were not suitable as both the costs (inputs) and the products were counted in natural units.

Hence, goals had to be formulated by the way of some sort of price system, and so we used a number of comparative value systems. "Price systems", in this case, were needed only for the analysis of the system and not for the determination of some sort of a profit.

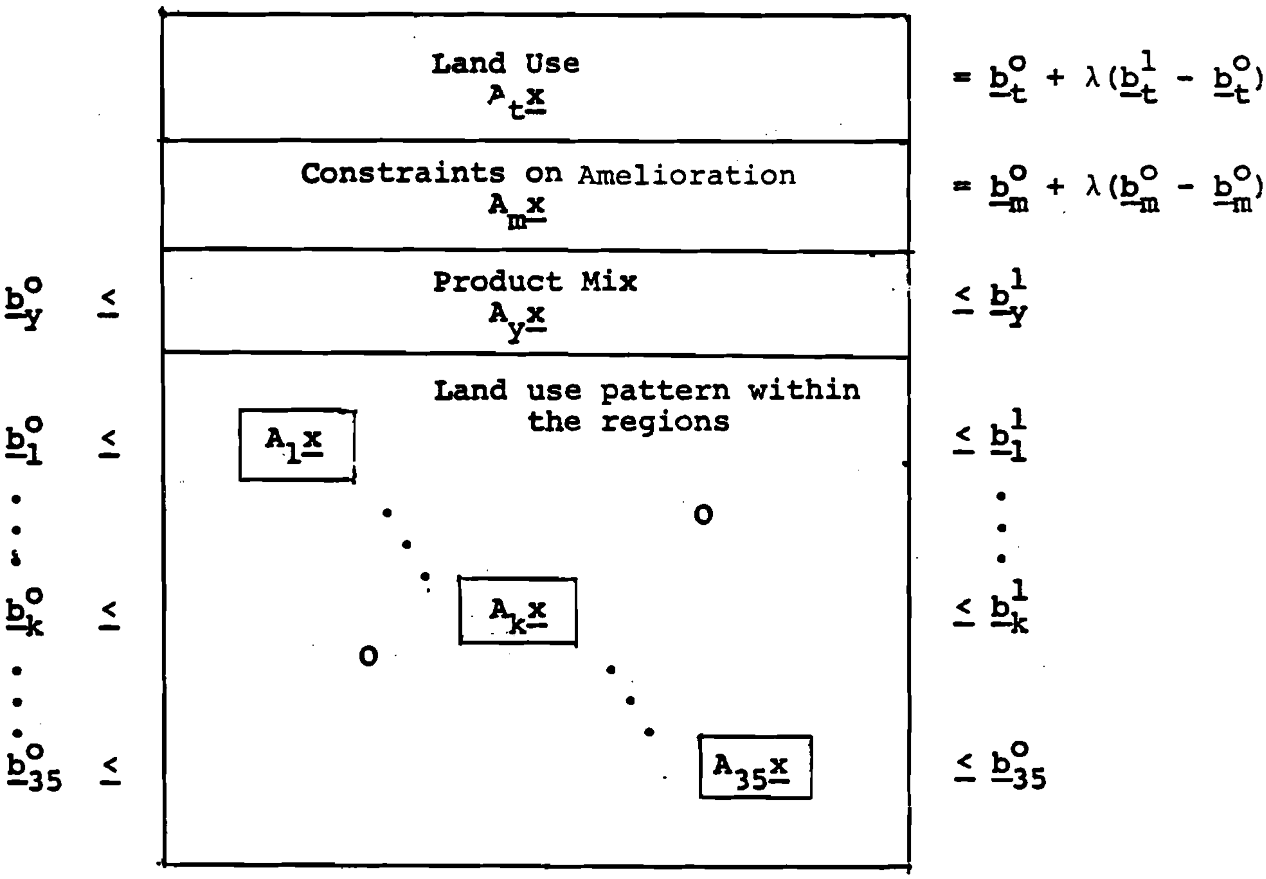

Figure 5. Structure of the outlined model.

The comparative value systems were based on some indicator of the internal content of the products like e.g. protein content, energy content, grain unit and so forth, and then the optimal product and land use structures under the different limitation levels were analized.

Obviously, as a consequence of the extreme characteristics of these value systems, it is impossible and unfavorable to realize production structures that are optimal with respect to them, but such results are interesting in themselves, as they show maximal possibilities in certain directions. Knowing these maximal possibilities, compromise solutions with respect to certain groups of the goal functions (or to all of them) were also determined.

Before turning to problems of modelling the impacts of technological development in the methodology of the Hungarian Task 2 Case Study it is essential to recall the main hypotheses underlying the agroecological survey project.

(1) Possibilities offered by genetic development are not limited by agricultural technology. Forecasts were prepared by supposing that the most advanced present technology becomes general.

(2) All the required fertilizer, pesticides and herbicides will be available. A special study was made on the nutrient requirements of a production on the forecasted level. The frequency and expected intensity of the appearance of different pests and weeds was determined together with the expected production losses in the absence of the appropriate protection measures.

MODEL PROPOSAL FOR THE REGIONAL ALLOCATION OF AGRICULTURAL INVESTMENT

In our opinion the objectives of the Hungarian case study can be realized by using a hierarchic model system consisting of the following three levels:

(1) The determination of a long-term production policy and the description of genetic and technological progress.

(2) Investment policy;

(3) Production on the regional level.

The structure of the system is shown in Figure 6.

Consideration of the first level is omitted here. This is the level at which the forecasting of the price system, investment constraints, the needs of society and of genetic and technological development takes place. With the single exception of technological prognosis, all these factors can be regarded as solved, the economic factors being provided by HAM and the genetic prognosis by the Survey of the Agroecological Potential. Linkages with the rest of the model system are yet to be worked out.

The model to be presented here deals with the long-term planning of agricultural investment, which constitutes the second level of the model system.

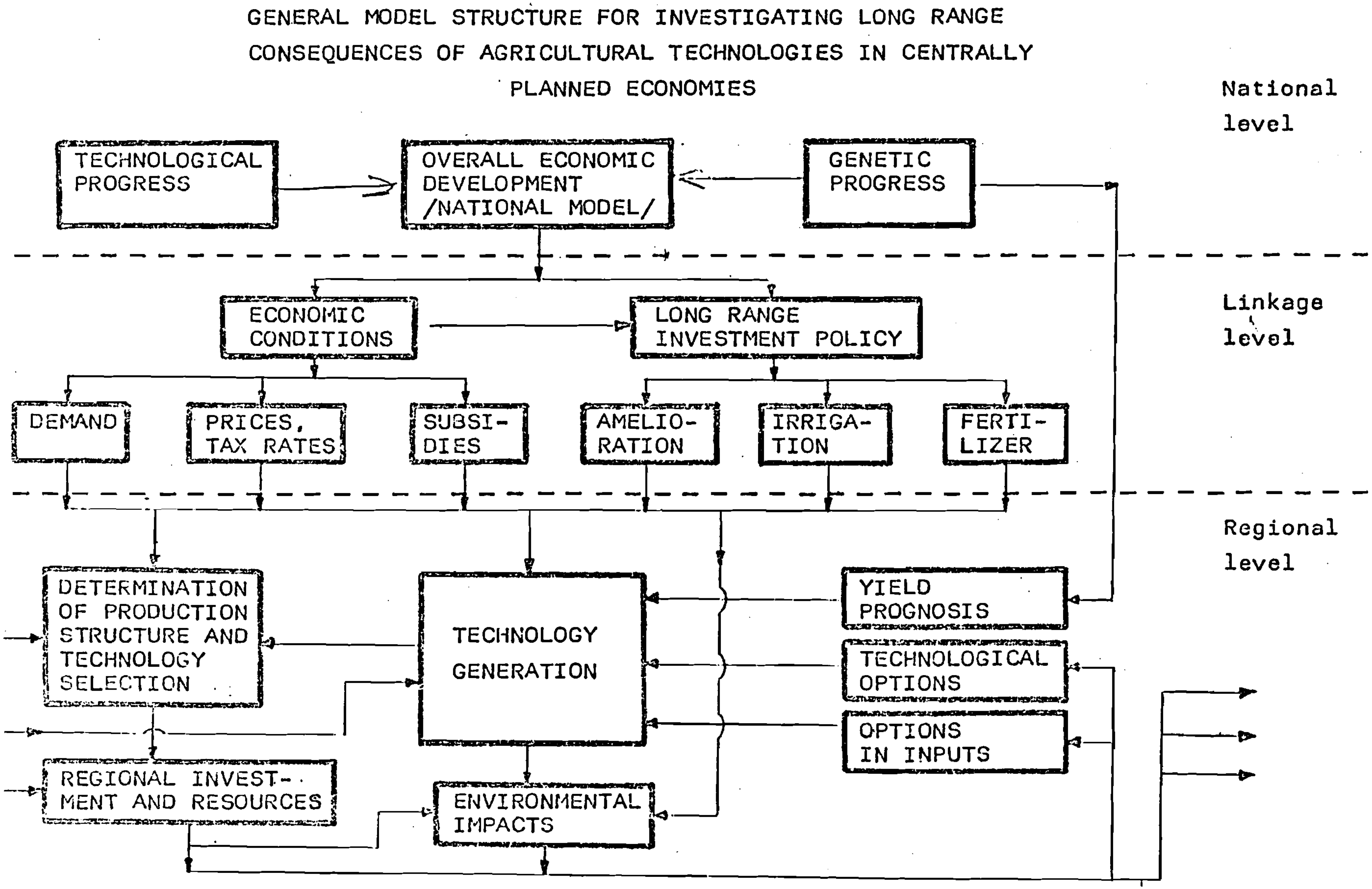

Figure 6. Structure of the system.

The third level serves to investigate production in individual regions, the quality of the habitat, technological effects, and other factors to be taken into account.

THE INVESTMENT MODEL

The basic hypothesis is that within the framework of Hungary's centrally planned economy, investments influencing the quality of the habitat - e.g. amelioration, irrigation - are financed by the government on the basis of long-term plans.

The production, import and distribution of fertilizers and plant protecting agents are also controlled by the government. Raw materials such as phosphorus, potassium, and other materials containing energy are imported. These factors which exert a direct influence on production and are centrally financed must be considered together with the above investments. This allows us, on the one hand to investigate and compare the long-term consequences of policies such as an increased use of chemicals to achieve higher yields more rapidly, to the detriment of ameliorative investments, and on the other, to emphasize the improvement of soil fertility, which would in turn mean a slower but more durable rise in production capacity.

The long-term investment policy is described by a control problem, the different investment policies constituting the set of possible controls. The criterion of optimality ensures a certain type of development which is considered by specialists as desirable.

The expression of long-term development in monetary terms is rather difficult. Therefore we should formulate the goal to be achieved in natural units. Development curves for yields based on the genetic prognosis of the Agrecological Potential Survey provide us with an excellent opportunity to do this.

The development curves of the following crops could be used as reference curves:

- maize
- wheat
- protein crops (soybeans, peas, sunflowers)
- fodder crops (alfalfa, red clover)
- pastures.

Although pastures play a special role in land use, they may be handled together with fodder crops.

Production of the above listed crops is of determining importance for the whole of agriculture, including animal husbandry. (These cultures cover about 80% of the total agricultural area). They cannot be further aggregated as their different habitat requirements must not be left out of consideration.

After this short introduction, let us turn to the formal description of the model.

Notations:

t - the time, $t \in \{1,2,...,T\}$

n - the index standing for the reference crop, $n \in \{1,2,...,N\}$

k - the index of the region, $k \in \{1,2,...,K\}$

l - the index of the investment sector, $l \in \{1,2,3\}$

with

$l = 1$ for the chemicals
$l = 2$ for amelioration
$l = 3$ for irrigation

m - the index representing the quality of the habitat, $m \in \{1,2,3\}$

with

$m = 1$ for the present state
$m = 2$ for the state after melioration
$m = 3$ for the state of an irrigated and relaimed habitat

$\hat{u} \in R^{T.K.3}$ - an investment vector

$U \cdots R^{T.K.3}$ - the set of the possible investment vectors

$\hat{u} = (\underline{u}(1), \underline{u}(2), ... \underline{u}(T))$

$\underline{u}(t) = \{u_{k,l}(t)\}_{k,l}$

$\hat{x} \in R^{T.K.3}$ - the state vector of the habitat

$\hat{x} = (\underline{x}(1), \underline{x}(2), ... \underline{x}(T))$

$\underline{x}(t) = \{x_{k,m}(t)\}_{k,m}$

$\hat{z} = (\underline{z}(1), \underline{z}(z), ... \underline{z}(T))$ - the vector describing the structure of production

$\underline{z}(t) = \{z_{k,m,n}(t)\}_{k,m,n}$

with

$z_{k,m,n}$ meaning the area occupied by the n-th crop, in the k-th region, on the m-th soil type

$\hat{v} = (\underline{v}(1), ... \underline{v}(T))$ is related to the land use,

with

$\underline{v}(t) = \{v_{k,m,n,j}(t)\}_{k,m,n,j}$

$z_{k,m,n}(t) = \sum_j v_{k,m,n,j}$

where j represents the level of fertilizer application.

Centrally financed agricultural investments are allocated to regions and sectors in each period. It is expedient to use relatively large regions numbering between 4 and 7. Melioration, irrigation and chemicals are the sectors. The allocation of investment resources is described by a system of linear inequalities:

$$B\,\underline{u}(t) \le \underline{b}(t) \qquad t \in \{1,\dots,T\}$$

The rows ensure, among others, that capital limitations are not exceeded and certain proportions between the investments in the different regions and sectors are maintained:

$$\sum_{k,l} u_{k,l}(t) \le \beta_o(t)$$

$$\beta_k^1(t) \le \sum_l u_{k,l}(t) \le \beta_k^2(t)$$

$$\bar{\beta}_l^1(t) \le \sum_k u_{k,l}(t) \le \bar{\beta}_l^2(t)$$

Other constraints can also be considered. Then the set of the possible investments, U is of the form:

$$U = \{\hat{u};\hat{u} = \underline{u}(1),\dots\underline{u}(T)\},$$
$$B\,\underline{u}(t) \le \underline{b}(t), \quad t \in \{1,\dots,T\}\}$$

The state of the system is given by the state vector of the habitat.

The following two possible variants of different complexity exist:

(a) a variant accounting for an average deterioration of the habitat;

(b) another considering the land use of the previous production period.

Let us turn to the first variant. The quality of the habitat is, in this case, determined by the state prevailing in the previous period and by the investments of that period. This is described in a concise form by the system of difference equations:

$$\underline{x}(t+1) = A\,\underline{x}(t) + C\,\underline{u}(t) \qquad t \in \{1,\dots,T\}$$
$$\underline{x}(0) = \underline{x}_o$$
$$\underline{0} \le \underline{x}(t) \le \underline{L} \qquad t \in \{1,\dots,T\}$$

Here $\underline{x}_o$ denotes the initial state of the system and the inequality stands for the natural limitations in the habitats, like e.g. for the fact that irrigation is only possible in the plains or for area limitations due to the amount of available irrigation water. The Survey of the Agroecological Potential contains the data required here.

Deterioration in habitat quality is considered independent of production and is expressed in terms of the decrease of the area of available land. The main relationships take the form:

$$x_{k,1}(t+1) = x_{k,1}(t) + \sum_{m=2}^{s} \alpha_{k,m}\, x_{k,m}(t) - \sum_{l=2}^{s} \frac{u_{k,l}(t)}{s_{k,l}(t)}$$

$$x_{k,m}(t+1) = x_{k,m}(t) - \alpha_{k,m}\, x_{k,m}(t) + \frac{u_{k,l}(t)}{s_{k,l}(t)} \qquad m = 2, 3;\ l=m$$

$$0 \le x_{k,1}(t) \le \sum_{m=1}^{s} x_{k,m}(0)$$

$$0 \le x_{k,m}(t) \le L_{k,m}$$

$$k \in \{1, \cdots, k\};$$

where $\alpha_{k,m}$ is a coefficient related to the deterioration of the habitat and $s_{k,m}(t)$ is the cost of a melioration or irrigation project for one hectare.

The second variant takes the production structure of the individual production periods into account. The deterioration of the habitat depends on the land use, hence this variant would probably give a more realistic picture. As the cultivation of field crops damages the conditions of production, ameliorative interventions are needed from time to time. On the other hand, a period when the land is given over to pasture is favorable in terms of soil productivity.

If we consider all these factors, the state of the habitat is governed by the following system of difference equations:

$$\underline{x}(t+1) = A\,\underline{z}(t) + C\,\underline{u}(t)$$

$$\underline{x}(0) = \underline{x}_0$$

$$\underline{0} \le \underline{x}(t) \le \underline{L} \qquad t \in \{1, \cdots, T\}$$

where the production structure in the t-th period is described by the vector $\underline{z}/t/$.

Using the relationship

$$\sum_{n} z_{k,m,n}(t) = x_{k,m}(t)$$

the difference equations are to be modified to the form:

$$x_{k,m}(t+1) = \sum_{n} z_{k,m,n}(t) - \sum_{n} \alpha_{k,m,n}\, z_{k,m,n}(t) + \frac{u_{k,l}(t)}{s_{k,l}(t)}; \quad m = 1$$

Similar modifications are to be carried out in the case of the rest of the relationships.

It is, in fact, this second version that points out the dependence of the state of the system on the previous state, the investments and the actual land use. In this case, the set of possible production structures, given an investment policy u, is of the following form:

$$\Omega(\hat{u}) = \{\, \hat{v}\,;\ D(t)\,v(t) + E\underline{x}(t) + F(t)\,\underline{u}(t) \le \underline{f}(t),\ \underline{v}(t) \ge \underline{0}\ , \qquad t \in \{1, \cdots, T\}\}$$

The matrix D/t/ contains the information about the growth of the yields due to genetic progress, the biological constraints of the production, the dependence on the level of fertilizer application etc.

The matrix E gives the area constraints, F/t/ the limitations of fertilizer use, and the vector $\underline{f}$/t/ contains the lower and upper bounds of the product and production structure. In detail, this means the following system of equations:

(a) area constraints:

$$\sum_{j,n} v_{k,m,n,j}(t) \le x_{k,m}(t)$$

$$v_{k,m,n,j}(t) \ge 0$$

(b) limitations on the amount of fertilizers:

$$\sum_{m,n,j} v_{k,m,n,j}(t)\, q_{k,m,n,j}(t) \le u_{k,1}(t)$$

(c) constraints of the production:

$$f^{(1)}_{k,n}(t) \le \sum_{m,j} d_{k,m,n,j}(t)\, v_{k,m,n,j}(t) \le f^{(2)}_{k,n}(t)$$

where $d_{k,m,n,j}$/t/ denotes the yield of the n-th crop in the k-th region, on soil type m and on the j-th level of fertilizer application.

(d) constraints of the land use

$$T^{1,n_2}_{k,m,n_1} \cdot z_{k,m,n_1}(t) \le z_{k,m,n_2}(t) \le T^{2,n_2}_{k,m,n_1}\, z_{k,m,n_1}(t)$$

Of course, further constraints may also be imposed.

Let

$$Y_n\,(u(t),x(t),v(t))$$

denote the national average yield of the n-th crop under control u(t) in the state x(t) with the land use v(t) in the t-th year, and let

$$Y_n(\hat{u}, \hat{x}, \hat{v}) = (Y_n(u(1),x(1),v(1)), \cdots ,Y_n(u(T),x(T),v(T))).$$

And also, let the vector

$$Y^o_n = (Y^o_n(1), \cdots ,Y^o_n(T))$$

describe the reference curve for the development of the yield of the n-th crop.

Y_n is usually called a transfer function, a function expressing the nonlinear dependence of the yields on $(\hat{u},\hat{x},\hat{v})$.

The deviation of the actual yield trajectory and the reference trajectory is measured by the function

$$h_n(Y^o_n, Y_n(\hat{u}, \hat{x}, \hat{v})) = \sum_{t=1}^{T} \rho^+_{n,t}\,[Y^o_n(t) - Y_n(\underline{u}(t),\underline{x}(t),\underline{v}(t)]_+ - \sum_{t=1}^{T} \rho^-_{n,t}\,[Y_n(u(t),x(t),v(t)) - Y^o_n(t)]_+$$

where $\rho^+_{n,t}$ and $\rho^-_{n,t}$ are positive numbers, used for the weighting the deviation of the two trajectories.

Maximizing h_n means the search for an investment policy leading to an actual yield trajectory that is higher than the reference curve at the most possible values, and at values where it remains below the reference curve, the difference is the least possible. Even if we prescribe only one single reference curve, the goal is the ensurance of a balanced development in time and the system does not tend to achieve local maxima within shorter periods. It is expedient, however, to consider all the listed crops and to use a multi-objective optimization approach. This avoids the possibility of an uneven development of the production structure.

Let us introduce the notation:

$$h(Y^o, \underline{Y}(\tilde{u}, \tilde{x}, \tilde{v})) = (h_1(Y_1^o \cdot Y_1(\tilde{u}, \tilde{x}, \tilde{v}), \cdots, h_N(Y_N^o, Y_n(\tilde{u}, \tilde{x}, \tilde{v}))$$

The task is to find a control $\tilde{u}_o \in U$, a state $\tilde{x}_o$ and a production structure $\tilde{v}_o$, with

$$\underline{h}(Y^o, \underline{Y}(\tilde{u}_o, \tilde{x}_o, \tilde{v}_o)) \geq \underline{h}(Y^o, Y(\tilde{u}, \tilde{x}, \tilde{v}))$$

being valid for all the possible controls $u \in U$, the respective state $\tilde{x}$ and production structure $\tilde{v} \in \Omega(\tilde{u})$. This means, in other words, that $(\tilde{u}_o, \tilde{x}_o, \tilde{v}_o)$ is a Pareto-optimal point for $\underline{h}$.

Special investigations are needed to solve the problem of selection from the set of Pareto-optimal solutions.

SUMMARY.

The long-term investment policy can be described by a control problem, where the set of possible controls is given by a system of linear inequalities

$$B\underline{u}(t) \leq \underline{b}_o(t) \qquad t \in \{1, \cdots, T\}$$

The state of the system is determined by a linear system of difference equations

$$\underline{x}(t+1) = A\underline{z}(t) + C\underline{u}(t)$$

$$\underline{0} \leq \underline{x}(t) \leq \underline{L} \qquad t \in \{1, \cdots, T\}$$

$$\underline{x}(0) = x_o$$

The transfer from the controls to the yields is described by a system of linear inequalities and a non-linear function.

$$\Omega(\tilde{u}) = \{ \tilde{v};\ D(t)\,v(t) + E\,x(t) + F(t)\,\underline{u}(t) \leq \underline{l}(t)$$

$$\underline{v}(t) \geq 0, \quad t \in \{1, \cdots, T\} \}$$

$$\underline{Y} = \underline{Y}(\tilde{u}, \tilde{x}, \tilde{v}),$$

and the solution to the problem

$$P - \max_{u \in U} \underline{h}(Y^o, Y(\tilde{u}, \tilde{x}, \tilde{v}))$$

$$\tilde{v} \in \Omega(\tilde{u})$$

is sought, with P-max standing for the Pareto optimality.

That is to say that the goal is: to follow certain prescribed reference trajectories instead of the determination of local maxima. Such a formulation of the problem allows us to develop a long-term investment policy. The setting up of a number of objectives ensures a balanced development.

Finally, we should like to point out that the above outlined method allows the use of alternative reference trajectories and the carrying out of investigations into the determination of investment policies that reckon with such emergency situations as e.g. a sudden, substantial decrease in fertilizer supply. These investigations are to be carried out together with a sensitivity analysis.

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