METHODOLOGY FOR THE INVESTIGATION OF LONG TERM CONSEQUENCES OF TECHNOLOGICAL DEVELOPMENT IN HUGARIAN AGRICULTURE--AN IIASA/FAP TASK 2 CASE STUDY

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PREFACE

Task 2 of the Food and Agriculture Program "Technological Transformations in Agriculture: Resource Limitations and Environmental Consequences" initiated a number of case studies in various countries with differing socio-economic and natural conditions. Problems of technological development are influencing potential production in selected regions. The expected environmental implications will be studied at various levels of detail and under various conditions. One of the case studies already under way is in Hungary and is oriented towards covering the whole country, region by region. It is of particular interest since Hungarian scientific institutions developed the Hungarian Agricultural Model in extended collaboration with Task 1 of the FAP over the past few years. This provides a good opportunity for the Task 2 case study to further link both (national and regional) levels of analysis.

This paper describes the first phase of the study, the problem, the formulation of goals, and the basic methodological framework.

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INTRODUCTION

Task 2 of IIASA's Food and Agriculture Program is concerned with the study of the long range consequences of technological development in agriculture. In order to carry out these investigations a series of case studies incorporating the region-specific nature of resource inputs and the environmental impacts of agricultural production is planned. A general methodological framework developed by J. Hirs and D. Reneau is being used as a starting point.

Two research projects were recently completed on the developmental problems of Hungarian food and agriculture. In cooperation with IIASA the second version of the Hungarian Agricultural Model (HAM-2) was completed in 1980. The model is focused on the economic aspects of the system; using HAM-2 mid-range (5 year) projections were made. In a research project organized by the Hungarian Academy of Sciences, agro-ecological factors were stressed. The main aim of the latter study was to explore the biological potential of production growth up to the year 2000. These two projects offer an excellent starting point for further investigations in which the economic, technical, ecological and environmental elements of agricultural development would be equally considered.

In Hungary it was decided that work in this direction be continued within the framework of a new research project on the use of Hungary's natural resources directed by Academician Istvan Lang. In October 1980 the decision was made that this study would be considered as one of the Food and Agriculture Program (FAP) Task 2 Case Studies. Details of cooperation were discussed on various occasions. The methodological guidelines of the Task 2 research group of the FAP were accepted by the Hungarian team, and the specific objectives of the Hungarian research plan were approved of by IIASA.

In the Hungarian case study producing regions within the country are treated as basic units of investigation. A region is the framework within which the major technical, technological, ecological and physical processes will be studied. However, the whole country will be covered region by region and conclusions will be drawn on the national level as well.

The Hungarian case study is being coordinated by the Food and Agriculture Subcommittee of the Hungarian National Member Organization (NMO) responsible for the coordination of Hungarian collaborative efforts with IIASA. The centers of actual work are: The Research Institute on National Planning, the Bureau for Systems Analysis, the Department of Agricultural Economics at the Karl-Marx University of Economic Sciences, and the Institute of Soil Sciences of the Hungarian Academy of Sciences. Work was conducted by a team of researchers including the authors of this paper and C. Forgacs, A. Jonas, K. Kelemen, I. Ladunga, F. Rabar, M. Sebestyen, and F. Toth.

The purpose of this paper is to present the first results of the Hungarian case study. The methodology of the study, the regional-national recursive model-system developed for the investigation is described in this Working Paper. The model is now at the intermediate stage of development, but as yet no actual data has been run. We hope that this report will stimulate discussion and feedback which may then be incorporated in future versions of the model.

During the development of the model as it is presented here we benefited much from the comments and proposals of members of the Task 2 group, Dr. K. Parikh, Dr. J. Hirs and Dr. A. Por also at IIASA, and other colleagues at the Institute of Soil Sciences in Budapest. Many thanks are also due to Julia Czekierska for editing and typing this manuscript.

THE PRESENT STATE OF HUNGARIAN AGRICULTURE

Hungary is situated almost exactly in the center of Europe. Its climate is continental in character and the natural conditions for agriculture are in general very favorable. Agriculture has developed at a relatively high rate in recent years and the overall tendencies in agricultural development have generally not been questioned. However, the last few years have presented some problems concerning the relationship between the environment and agriculture, and the impacts of increasing energy prices are becoming more and more visible.

The Major Characteristics of Agricultural Production

Traditionally agriculture has always played an important role in the Hungarian economy. However, in spite of a total increase in agricultural production, % of agriculture in gross and net national production has decreased. (In 1978 agriculture contributed 16% to the total net national production of the country.) Over the last few decades Hungarian agriculture has developed relatively rapidly. Between 1961 and 1965 total agricultural production increased at a rate of 1.4% yearly compared to the average rate of the preceding five years; from 1966-1970 the increase was 3%, and from 1971-1975 3.5%; from 1976-1980 growth occured at a rate of 3%. According to data from the World Bank, Hungary ranked second after the Netherlands in the growth of food production during the above mentioned period.

With a few exceptions the production of major agricultural products has increased significantly (see Table 1). Substantial results have been achieved especially in the growth of wheat and crop production. 20 years ago an agricultural worker produced food for 5-6 persons; now he produces enough for 11-12 people at an incomparably higher level of supply (see Table 2), while at the same time agricultural and food exports have also multiplied. The Hungarian food sector has a favorable balance of payments in foreign trade both in the west and in the CMEA countries. In 1979 approximately 21% of the total exports from Hungary were of agricultural origin, whereas the same sort of products made up only 8% of the total value of imports.

The 1970's brought considerable changes to the technologies used in agricultural production. Highly mechanized crop production methods became widely used and significant developments took place in animal husbandry, as well as in the construction of large scale poultry plants, pig-fattening farms, feed-lots and dairy farms. Due to large scale mechanization in Hungarian agriculture, the overall power capacity of machinery reached the 1000 kw/ha level in 1978. Most of the operations in field crop production are fully mechanized including the spreading of about 300 kg/ha of chemical fertilizers. Due to climatic conditions, irrigation does not play an important role at present. Changes in production technologies and the use of new crop and animal varieties have significantly increased yields, with the exception of a few products, and as a result, agricultural production in Hungary is comparable with that in other developed countries.

Cooperative farms play an important role in Hungarian agriculture (Table 3). Agricultural producers' cooperatives in Hungary are not just a type of large-scale farming, but the primary and determinant form of the socialist agricultural enterprise. Cooperatives fulfil their obligations towards society, while the socialist state guarantees their independence in a legal framework, helping and controlling them in their activities. The state asserts social interests in cooperatives by using methods of socialist planned economy, economic influence and regulation, state supervision and control. Public authorities do not intervene in the farming activities of cooperatives, i.e. do not try to manage in their stead. The independence of cooperatives is asserted - as is that of the state enterprises - within the system of socialist planned economy, in which, however, the priority of national level decisions and plans over those of the cooperatives (enterprises) is guaranteed.

State enterprises and coooeratives possess equal rights; their relationship is based upon mutual advantages and risks. State enterprises have no authority over the cooperatives. Since

Table 1. Main indicators of agricultural production in Hungary

Denomination	1938	1950	1960	1970	1975	1978
Total gross output (%)	113	100	120	146	183	201
of which:						
plant cultivation (%)	121	100	121	135	177	186
livestock raising (%)	101	100	118	162	193	221
National income produced (%)	106	100	102	98	110	111
Wheat (1000 tons)	2688	2085	1768	2723	4005	5678
Corn (1000 tons)	2662	1820	3543	4072	7088	6581
Sugar beet (1000 tons)	969	1640	3370	2175	4089	4192
Vegetables (1000 tons)	739	1009	1364	1517	1632	1945
Fruit (1000 tons)	310	587	737	1308	1355	1392
Grapes (1000 tons)	495	611	491	743	813	786
Beef-cattle (1000 tons)	751	893	1070	1343	1848	1957
Milk (million litres)	1525	1403	1899	1807	1920	2266
Eggs (million)	844	955	1848	3280	4001	4748

SOURCES: Agricultural Statistical Pocketbook 1979
Hungarian Statistical Pocketbook 1980

Table 2. Per head consumption of food and nutrients

	1970	1975	1979
Meat total (kg)	60.4	71.2	73
Milk and dairy product* (kg)	109.6	126.6	157
Eggs (pc)	247	274	324
Fats, total (kg), of which	27.7	29.1	30
butter (kg)	2.1	1.7	2
cooking-oil, margarine (kg)	2.8	4.6	6
Flour (kg)	124.1	117.9	118
Rice (kg)	4.1	4.3	4.4
Potato (kg)	75.1	66.8	60
Sugar (kg)	33.5	39.4	36
Coffee (dkg)	164.5	261.4	270
Tea (dkg)	7.2	8.1	9
Wine (litre)	37.7	34.2	35
Beer (litre)	59.4	72.3	86
Spirits* (litre)	5.4	7.2	9
Tobacco (kg)	2.2	2.3	2.2
	Daily nutrient consumption		
Calories	3,098	3,242	3,250
Kilojoule (kJ)	12,971	13,574	13,600
Protein (gramme)	97.9	100.7	103.5
Fat (gramme)	115.5	127.7	133.0
Carbohydrate (gramme)	419.2	425.1	411.0

* without butter

* converted into 50 proof spirit

SOURCE: Hungarian Statistical Pocketbook 1980

Table 3. Number and average size of the state farms and cooperative farms

		State farms			Cooperative farms		
		1960	1967	1976	1960	1967	1976
	Number of farms	333	210	141	4507	3033	1425
per farm	Agricultural hectarage	2597	4287	5826	765	1463	3120
	Value of fixed assets, in million Ft	48	119	286	2	15	73
	Employment, heads	518	794	999	212	239	420
	Gross value of production, in million Ft	27	46	115	6	11	41
	Net value of production, in million Ft	10	6	22	3	4	12

SOURCE: Központi Statisztikai Hivatal, Mezőgázdasagi statisztikai zsebkönyv... (Central Statistical Office. Statistical pocket book of agriculture..) Budapest, 1969 to 1977. Statisztikai Kiadó. 1969, pp. 6, 220, 227; 1945-1975, pp. 16, 48, 174; 1977, pp. 25, 34, 50, 129.

the further progress of the advanced socialist society does not necessitate a radical change in socialist ownership, but the strengthening and further development of state and cooperative ownership, cooperatives will continue to develop in conformity with their social and economic role in the future.

In Hungary large-scale agricultural farming is organically linked to small-scale farming. Contrary to the practice and theory accepted in other socialist countries during the period 1959-1961 when cooperatives were organized, household farming has become a form of small-scale farming indispensable to the supplying population and well utilizing peasant capacities in Hungarian agrarian development. Agrarian policy has always considered household farming as an organic part of socialist agricultural production. After a certain indecision in the mid-1970s this concept and practice were further strengthened during the last 5-6 years. The main point is that socialist agricultural production relies both on large-scale and small-scale production and, though large-scale farms have the bigger share, small farms also play an indispensable role.

The Trend of Increasing Energy Consumption in Agriculture

Agricultural production represents one of the most ancient types of human productive activity. Besides plants and livestock, the natural environment and men equipped with at least primitive means are present in the traditional production systems of agriculture. The productive forces have radically transformed this system for the most part in the industrialized countries by complementing it with new elements and by reforming it fundamentally with respect to its interrelations. On the one hand, machines and technical equipment are replacing human labor at an ever growing extent; on the other hand, man, who controls production, intervenes in the biological processes themselves by replacing certain parts of them with technical-chemical improvements, which will prove more advantageous in one way or another to the producer.

The replacement of human labor by machines and technical means is already very advanced in the agriculture of the developed countries. Intervention in the natural biological processes, however, is also important and it occurs to a great extent. As demonstrated in the examples given in Table 4, man is more and more able to replace a considerable part of the biological processes which form the basis of production by artificial means which are better suited to the aspects of large-scale production. The battery system of egg production presents an excellent example of the current stage of this progress. In the case of the egg-laying hen, practically all the animal functions of life - even those which could eventually be performed by the birds themselves. - can be replaced by artificial means, except the production of eggs and the basic metabolisms (breathing, digestion, etc.). Food and water are supplied by automatic equipment at just the required temperature; illumination, moisture content and the removal of eggs are similarly taken care of. The eggs are selected by machines and, instead of being brooded by the hen, are brooded in incubators. The biological processes were restricted to the hen and to the animal metabolisms.

The above mentioned changes which took place in agricultural production can be summarized as the replacement of human labor and natural biological processes by means of utilizing energy of nonagricultural origin. Mechanization, as well as increased use of fertilizers and the application of plant protecting chemicals are after all newer forms of energy demand. Modern agricultural production is characterized by a particularly high level of inputs of nonagricultural origin which can finally be reduced to energy. The energy consumption of the corn production technology applied in the United States of America - which can be seen in Table 5 - is more than a hundred times greater than the energy input of Mexican corn production. An indication of the magnitude of the energy demand of modern technologies is given by the fact that the 30,034 x 10^6 joule consumption per hectare of USA corn production (detailed in Table 5 according to diverse components) can be supplied only by the consumption of energy materials equivalent to 700 kg of mineral oil.

Table 4. Biological processes and artificial methods of replacement in agricultural production

Natural biological process	Replacement method
Eggs hatched naturally	Electrically or oil-fuelled incubator
Maintenance of soil productivity by natural means (crop rotation, root residues)	Fertilizing
Natural methods of feeding (pasturage)	Feedstuffs prepared and forwarded to the livestock
Natural resistance capability of the livestock	Protective immunisation
Natural biorhythm influenced by hormones	Artificial regulation of temperature, illumination and moisture content
Natural insemination	Artificial insemination

The energy consumption per unit acreage of agriculture in the developed countries (24.8 x 10^9 joule) is more than ten times greater than the same level in the developing countries (2.2 x 10^9 joule). Table 3, presents a brief survey of the level of agricultural energy consumption in diverse regions of the world. It is worth mentioning that - as can be seen in Table 5 - a considerable part of the inputs of the so-called "up-to-date" agricultural technologies is related to fertilizer use and chemicalization (as an average of the developed countries about 40 per cent of total agricultural energy inputs is of such type). A similar situation exists in Hungary where the share of chemicalization within the total energy consumption of crop growth amounts to 55 per cent.

The transformation of agricultural production systems outlined above has also been expressed by the large increase in mechanization, and the replacement of biological and natural processes by energy of nonagricultural origin, as well as an increase in the yields per unit acreage and generally in the volume of production. It is unambiguously proved in Table 6 that increased energy consumption is accompanied by higher yields. Energy consumption per agricultural laborer is highest in North America (556 x 10^9 joule), where production per agricultural laborer is also highest (67.9 tons in grain equivalent). A similar situation is demonstrated in Table 5. Energy inputs into US corn production, which are equivalent to 700 kg petroleum per hectare, are more than recovered by present yields, which are five times greater than those achieved under traditional production methods.

Table 5. Energy input in modern and traditional corn production

	Contemporary (USA)		Traditional (Mexico)	
	Per ha quantity	Per ha energy (10^6 joule)	Per ha quantity	Per ha energy (10^6 joule)
Inputs				
Machines	4.2 x 10^9 joule	4 200	173 x 10^6 joule	173
Fuels	206 litre	8 240	-	-
N fertilizer	125 kg	10 000	-	-
P fertilizer	34.7 kg	586	-	-
K fertilizer	67.2 kg	605	-	-
Seed corn	20.7 kg	621	10.4 kg	-
Irrigation	351 x 10^6 joule	351	-	-
Protective chemicals	1.1 kg	110	-	-
Herbicides	1.1 kg	110	-	-
Drying	1239 x 10^6 joule	1 239	-	-
Electricity	3248 x 10^6 joule	3 248	-	-
Transport	724 x 10^6 joule	724	-	-
Total:		30 034		173
Yields (kg per ha)	5 083		950	

SOURCE: Stout, B.A. 1979

The development trend of agricultural systems outlined above is generally considered as a positive one. The ready availability of energy resources at particularly low prices has rendered the large-scale increase of the consumption of energy of nonagricultural origin economical. At the same time this development has meant the reduction of the role of human labor in agriculture to a minimum. However, we are presently compelled to accept the fact that the world's energy reserves are limited and that the price of basic energy materials has risen astronomically and will continue to do so. The fact that environmental impacts are being more and more felt has meant that agricultural production planners cannot afford to simply talk about taking environmental protection measures; they will be obliged to adapt the technologies which they themselves have formulated accordingly. All these changes draw attention to the need to investigate and judge with more caution the future role of agricultural systems (those presently considered as being up-to-date) and the technologies applied within them. Whether the continuation of past trends in the development of agricultural technologies is justifiable or not must also be considered.

Table 6. Agricultural use of energy in diverse regions of the world

	10^9 joule per ha	10^9 joule per laborer	kg.per ha.	kg.per laborer	10^{15} joule 1972-1973	(FAO forecast) 1985-1986
<u>Developed countries</u>	24.8	107.8	3 100	10 508	4 637	6 329
North America	20.2	55.8	3 457	67 882	2 141	2 963
Western Europe	27.9	482.4	3 163	5 772	2 113	2 845
Oceania	10.8	246.8	976	20 746	137	192
Others	19.4	119.1	2 631	2 215	246	328
<u>Developing countries</u>	2.2	2.2	1 255	877	921	2 849
Africa	0.8	0.8	829	538	70	195
Latin America	4.2	8.6	1 440	1 856	313	845
Near East	3.8	4.4	1 335	1 386	168	581
Far East	1.7	1.4	1 328	781	370	1 228
<u>Socialist countries</u>	5.9	6.8	1 744	1 518	2 048	4 292
Asia	2.4	1.7	1 815	911	415	863
Eastern Europe and Soviet Union	9.3	28.5	1 682	4 109	1 633	3 429
<u>World Total</u>	7.9	9.9	1 821	1 671	7 606	13 470

SOURCE: Stout, B.A. 1979.

We think that this question can be justifiably raised for several reasons. Firstly it must be realized that agriculture is already an intensive sector of the economy at present. According to estimates (Dobrov and Randolph, 1978), 25 per cent of every kind of energy consumption all over the world is related to man's food supply. The food economy (including the entire food process right from the agricultural enterprises down to the consumers) ranks third behind the steel industry and petrochemistry in the sphere of total energy consumption. According to data provided by AGROINFORM, the Hungarian food economy's share of total energy consumption in 1978 was 11.4 per cent.

During the course of the past 30 years (1945-1975) in e.g. corn production in the USA, fertilizer inputs multiplied ten times, inputs related to irrigation increased 2.7 times, and transport inputs increased 4 times, whereas mechanization inputs doubled. Between 1960 and 1978 the energy consumption of Hungarian agriculture increased from 89 kg to 281 kg per hectare, i.e. 3.2 times (each energy material is expressed in terms of oil equivalents Thus those inputs requiring a high energy level increased and did so to such an extent that the yields could not keep pace. In the case of e.g. energy production in the USA, this means that compared to the increase of 3.15 times of energy inputs per unit acreage, the yield increase was only 2.4 times. However, the increase of Hungarian agricultural energy consumption by 3.2 times was accompanied only by a doubling of production between the years 1960 and 1978. Considering present energy problems the questions arises whether such a growth process can be continued in the long run or not.

Biological and Economic Efficiency

The above mentioned facts direct attention to the need to investigate the operative efficiency of agricultural production systems and their justification using new methods. We think, that, in addition to those indexes which were constructed based on the comparison of the economic efficiency of inputs, productive funds, as well as outputs, more importance should be attributed to those indicators of efficiency which reflect input-output relations expressed in physical units.

The transformation of inputs to outputs in agriculture fundamentally takes place in biological systems where plants and livestock are involved. The input-output relation expressed by the value indexes cannot be considered independently even in the most up-to-date production processes; in a practical sense it depends on the functioning of the biological systems and upon their efficiency. So, in addition to economic efficiency, we can also speak about the so called biological efficiency in agricultural production meaning the transforming capacity of the agricultural systems in a biological-physical sense. We must stress the idea that biological efficiency represents a particular indicator of the agricultural production systems, and it can be distinguished from the input-output indexes of the industrial production processes expressed in physical units by the role played by plants and livestock in production.

Biological efficiency can be expressed in terms of various types of indexes. Both inputs and outputs, i.e. the results of the production processes, are composed of several elements which can be compared either separately or in aggregated form, but the indexes may also vary according to the diverse spheres of agricultural production. The following index was formulated based on a comparison of inputs and outputs expressed in terms of energy equivalents, and seems to be suitable for the complex measurement of biological efficiency:

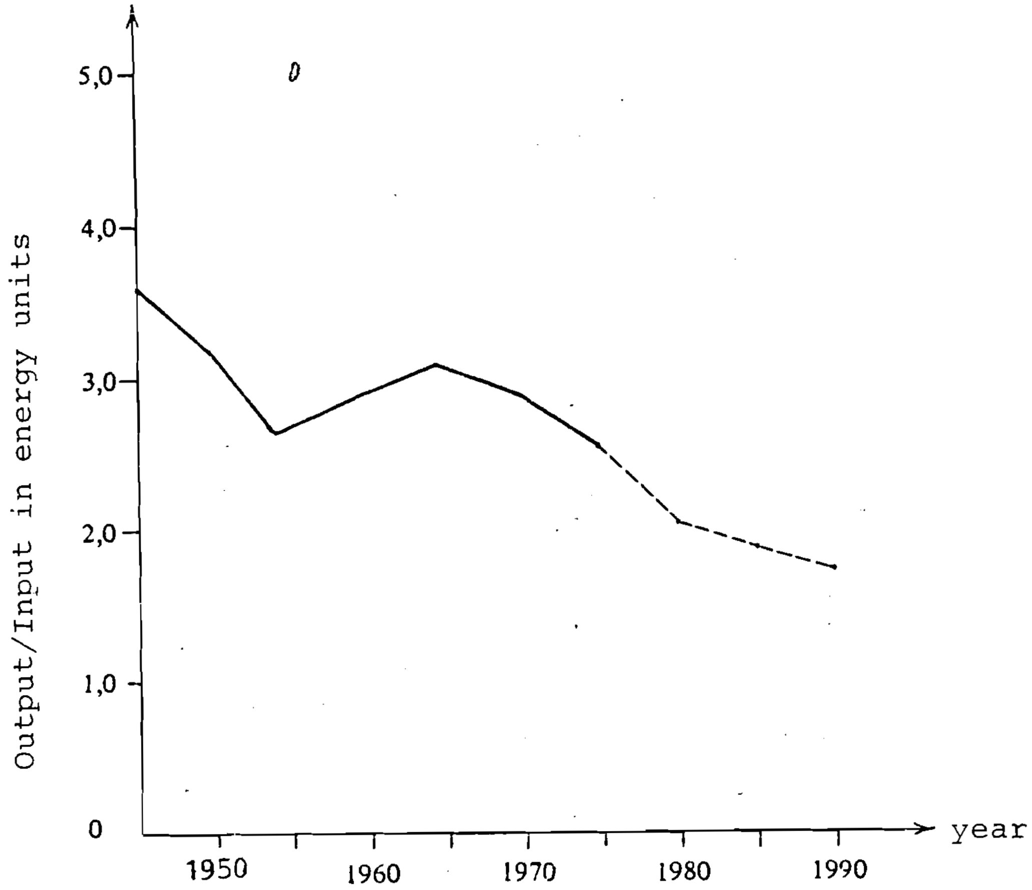
$$\text{coefficient of energy transformation (biological efficiency)} = \frac{\text{energy in the output (joule)}}{\text{energy in the inputs (joule)}}$$

This index expresses the outputs produced per unit energy input expressed in terms of energy equivalent; the operating efficiency of the biological system is thus characterized by the transforming capacity of energy. But other indexes of biological efficiency are also feasible, e.g. the comparison of feed consumption and weight gain of animals in livestock husbandry.

The coefficient of energy transformation allows a comparison of the biological efficiency of the diverse agricultural systems (Spedding. C.W.R. 1979). In Table 7 it can be observed that the transformation coefficient of livestock breeding is significantly smaller than that of crop growth. Feeding livestock with feedstuffs results in a drastic reduction of biological efficiency. In the case where the consumption of animal products surpasses the level recommended by dietetics a waste of our resources occurs. This fact should deliberately be taken into consideration when planning personal consumption or scheduling the development of consumer prices.

A survey taken of the chronological development of the coefficient of energy transformation in the production of one or another product is very instructive. Results published from diverse sources allow us to arrive at the conclusion that the development of agriculture in recent decades, i.e. the propagation of production methods entailing a high level of mechanization and chemicalization, was not accompanied by a corresponding improvement in biological productivity but rather by a reduction. Figure 1 shows the development of the coefficient of energy transformation in corn production in the USA. Similar Hungarian data are not at our disposal. Based upon available indexes of economic efficiency, the tendencies already mentioned and the data of Table 6, however, - according to which the outputs are relatively small in Eastern Europe and the Soviet Union compared to the level of energy consumption per unit acreage - it is not very probable that the tendency would differ significantly in Hungary.

This tendency is very thought provoking. Agricultural experts should regard this as a warning as it refers to the fact that the replacement of human labor, especially that of certain elements of the biological process, was carried out in such a way that it resulted in a decrease in efficiency with respect to the physical relation between the inputs entering the system and the produce



SOURCE: G.M. Dobrov-R.H. Randolph, 1978

Figure 1. Energy conversion rates in U.S. corn production

Table 7. Biological efficiency*in certain sectors of agriculture

Produce	Biological Efficiency
Rice	3 - 3.4
Grains	2.2 - 4.6
Corn	2.8 - 5.4
Potato	1.0 - 3.5
Milk	0.33 - 0.62
Eggs	0.16
Sheep-farming	0.39
Beef	0.18
Poultry meat	0.11

* Biological efficiency is defined as $= \frac{\text{energy content of product}}{\text{energy content of inputs}}$

SOURCE: C.R.W. Spedding, 1979
B.A. Stout, 1979

released from it. Cheap energy resources and the pursuit of profits obviously contributed to the fact that this replacement was carried out for reasons of immediate economic interest without due thought to the rational use of our limited natural resources. A similar situation existed in Hungarian agriculture but with the distinctive characteristic that several steps taken in the spirit of modernization did nothing to contribute to an increased economic efficiency.

It is incontestable that at a given moment economic efficiency is the most important aspect underlying judgements made concerning agricultural production systems. The value of the products can not be expressed by their energy content; several economic and other factors influence the way a consumer values a product as well as price fluctuations. So when comparing the diverse branches of production it must be noted that biological efficiency represents only additional information of secondary importance which cannot therefore serve as a basis for structural decisions. The problem of the development of livestock breeding or of crop growth e.g. can never be judged merely upon the basis of the coefficient of energy transformation. In our opinion, all the above points undoubtedly prove that an investigation of biological efficiency should play a greater role both in the comparison of development alternatives within a sector and generally in the elaboration of new technological alternatives.

The need for the greater improvement of biological efficiency obviously should not result in a decrease in production output nor should it lead to a failure to meet domestic demands. At the same time it is indisputable that the relations between biological and economic efficiency will be modified by changes taking place in the world economy, i.e. by the tremendous rise in energy prices. The results of an FAO survey related to US corn production which are presented in Figure 2, clearly demonstrate that in the case of e.g. the use of nitrogenous fertilizers together with present varieties and technologies, maximum output has already been achieved in the sphere of decreasing biological efficiency; in other words, that a decrease in biological efficiency begins before the maximum output has been attained. We can see that the optimum level of output can be realized using 225 kg nitrogen fertilizer, while optimum energy transformation occurs at a level of 135 kg per hectare.

Cheap energy prices determined a further increase in inputs which meant that the average input level was arrived at during the sphere of decreasing biological efficiency. It is not likely that this will become accepted as a reasonable standard or that we can state that: biological efficiency is becoming a more and more important determinant of economic efficiency. We must re-evaluate technologies which are generally applied and which are at present often accompanied by an inefficient use of energy resources. Because of rising energy prices, the reserves and potential of biological-natural processes, or even a return to traditional biological processes, should economic necessity dictate this, may be worth considering. Certain modifications in the development tendencies of agricultural production technologies, as well as efforts to produce more by biological means, can already be observed in several countries (e.g. the propagation of biological plant protection processes). It would be a mistake to delay the adoption of similar measures in Hungary. If this task were accomplished, it could contribute to the solution of our problems and help to realize our plans for a higher rate of efficiency.

OBJECTIVES OF THE STUDY

The aim of agricultural production is to satisfy mankind's demand for foodstuffs and other agricultural products. The inputs used to produce the necessary quantity and the use of resources in agriculture in a productive way depend on the basic functioning of the production systems, which also include material processes. The maintenance of the world's food supply at a constant level in view of the ever increasing population, is a formidable task in itself; the elimination of famine itself requires a further development of agricultural production. However, we must bear in mind that our resources are finite and limited in quantity. Man is compelled to use natural resources in a rational way and to avoid the unnecessary wastage which has occured so far, and more attention should be paid to increased environmental protection. In our opinion it is an absolute necessity to evaluate the types of agricultural technologies presently applied and to search for

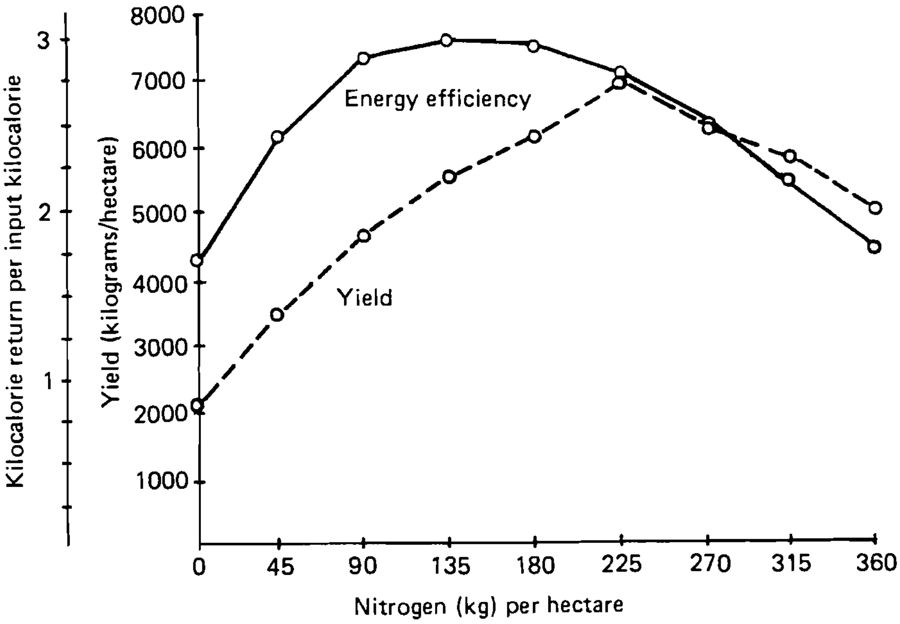


Figure 2. Yield and kilocalorie return per input kilocalorie for maize at different rates of nitrogen fertilizer application. Maize showed optimum yields with the application of about 200 kilograms of nitrogen fertilizer per hectare, whereas the optimum kilocalorie return per input kilocalorie resulted from an application of about 135 kilograms of nitrogen fertilizer per hectare.

the most preferable solutions with regard to future requirements in view of the situation mentioned above. During the course of this evaluation, a precise definition of our aims is as important as the explicit choice of those criteria which determine decisions to be made based on the results of technological development of a clearly material-technical and biological character. Firstly, the questions can be raised whether the introduction of technologies which cause an ever increasing energy demand should be continued, and whether the technological-technical tendencies of production development should be decided merely according to their economic efficiency in the short run. These are the questions which we endeavour to answer in our investigation.

The questions raised here were not answered by the two studies mentioned in the introduction. Neither the HAM project nor the agroecological study analyzed the economic, technical and environmental consequences of agricultural technological development in their full complexity, because this could not be envisaged at this level of detail.

The study of the impacts of agricultural technological development will include a whole range of problems. We will focus on the impacts on:

- -- the level of production, production growth;
- -- energy, especially nonagricultural support energy requirements;
- -- the natural environment, especially agricultural production potentials.

As major objectives of the study the following questions are being investigated:

- -- How to increase the productivity and efficiency of Hungarian agricultural production by using more rational combinations of existing technological alternatives;
- -- What are the production potentials of the existing soil resources, and how can these be increased and utilized?
- -- What are the economic consequences of an environment-protection oriented agricultural development?
- -- When, and under what circumstances, can energy become a limiting factor in technological development and production growth in Hungarian agriculture?

Obviously, these basic questions will bring many additional questions into our investigations. Of all these questions, the utilization of soil resources and related economic and environmental problems seem to be the most important issues, and therefore, this problem is emphasized in the study. In this respect we intend to answer the following type of question:

- -- How efficiently are existing technical, biological, and economic resources being used?
- -- What are the technical and economic possibilities of increasing the quality of different soil types?
- -- Can the increasing level of environmental protection limit the growth of agricultural production?
- -- What are the economic consequences of introducing technologies with more favorable environmental impacts?
- -- What possibilities do we have to introduce technologies based on the higher-level utilization of the potential of the original biological processes?

Parallel to the soil and environment oriented investigations, special emphasis is given to energy use in agriculture. Energy is becoming a major issue in several ongoing agricultural investigations in Hungary. We believe our study will contribute to these studies by trying to answer the following questions:

-- What is the projected energy requirement of Hungarian agriculture under the present developmental strategy?

-- Do we have any alternatives for decreasing energy inputs into agriculture, and what are the energy consequences of the various technological alternatives?

-- Can energy limit the production growth of agriculture and under what circumstances?

-- How efficient is energy transformation in Hungarian agriculture?

-- Can we contribute to the solution of the energy problem by changing the role of various energy types in agriculture?

-- Does Hungarian agriculture have any importance as an energy-producing system?

It is apparent that other problem areas could also be emphasized. But we intend to limit our work to the above-mentioned issues, in order to decrease the number of methodological and data problems to a manageable level.

THE GENERAL MODEL STRUCTURE

Within the framework of the above mentioned objectives, the study of "The long-term consequences of technological development in Hungarian agriculture" we endeavour to deal with the following major problems:

1. What kind of interrelations between the agrotechnics applied, the level of production and the changes which have taken place in the quality of the land can be demonstrated?

2. What kind of technological changes should be implemented to raise the level of production and to maintain and improve habitat conditions?

3. What long-term environmental conditions may accompany an economic policy where only the rentability of production is taken into consideration?

4. What long-term amelioration and irrigation policies can be implemented to gradually improve habitat conditions?

These four problems, of course, do not cover the entire sphere of problems to be investigated: we wanted to outline only the most important questions which determine the nature of the planned investigations and thereby draw attention to tne long-term context of the task.

The nature of the task renders an analysis of the processes of production, of land use and of technological change necessary over a long-term period, i.e. of about 20-25 years. Therefore, a feasible dynamic model system should be elaborated on three levels in order to facilitate its adaptation to the Hungarian planning system and to the economic processes practiced.

Using the experience gained from agricultural and ecological modeling work previously conducted in socialist countries, and the results of IIASA's methodological research on the centrally planned food and agriculture systems, as well as on the assessment of the long range consequences of technological development in agriculture, we intend to adopt a relatively new methodology for our study. This modeling framework will

- incorporate the basic features of the CMEA countries' agriculture;
- be consistent and comparable with other IIASA investigations on long range consequences of technological development in agriculture;
- include technical and environmental relations in a relatively detailed way;
- represent agricultural production by a set of relatively homogeneous regions;
- be detailed enough for use as an experimental tool for investigations into those questions posed;

and should also contribute to the further development of techniques applied in the planning and economic management of agriculture.

The main goal of the model development is not straightforward optimization, but to provide a tool for a detailed, many-sided, dynamic investigation of the consequences and limits of technological development in agriculture. On the whole the structure has a descriptive character. It reflects the present practice of technology selection and decision making in Hungary. At the same time various normative elements such as government decisions and plan targets are also considered. Use of the model might also allow for the calculation of the optimal state of some of the subsystems. Weather, animal disease conditions and other random effects could also be considered by means of various scenarios.

The model structure is outlined in Figure 3. The overall methodology used by the model is a simulation technique. The model is dynamic (recursive) with one-year time increment. The planned time horizon of the analysis is 20-30 years.

At the first or supreme level we fix those parameters and conditions which regulate the operation of the system. Considering the nature of the system, these parameters are functions of exogenous factors. They can be grouped into three classes.

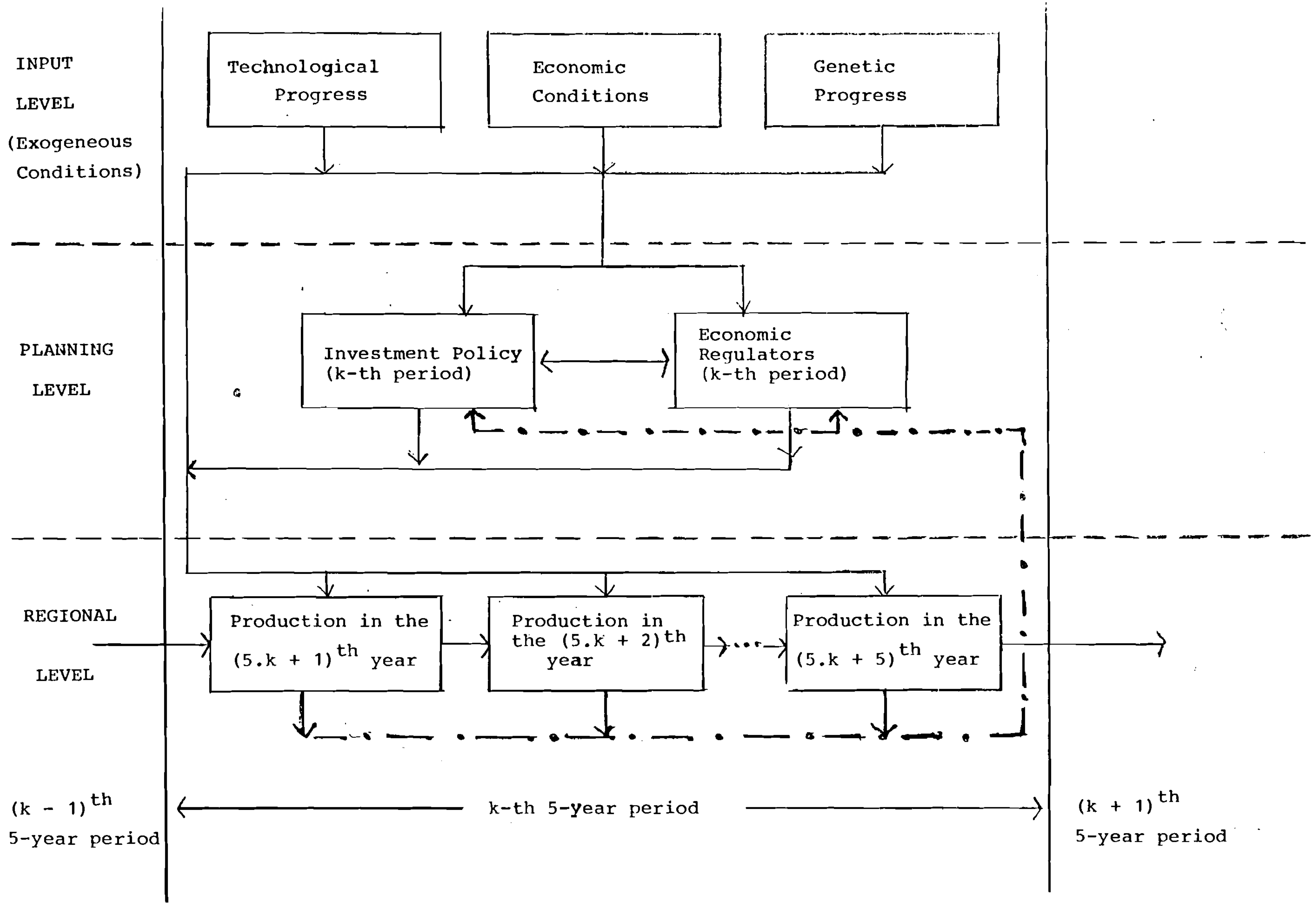


Figure 3. The structure of the Hungarian Task 2 Case Study

The first group is that of yield forecasts which reflect genetic development, the second represents the assortment of technologies presented by technological progress, and the third stands for national economic conditions.

The most important national economic parameters which are determinative for production over the short or long term are the following:

- price structure;
- product pattern (the lower and upper limits for the diverse crops calculated on the basis of domestic consumption and export possibilities);
- the aggregated sum of financial means available for the implementation of amelioration investments and for the production and purchase of fertilizers.

The parameters elaborated at the first level form the input of the system and they are not modified by the operation of the system. In the case of the last group of parameters this assumption is correct since the value of the parameters described above cannot be fixed in a system covering only agriculture or crop growing.

The purchase prices for technologies and energy, which render production possible, as well as the prices for commodities produced for foreign trade are fixed firstly by the international market and secondly by the production costs.

The second level simulates certain aspects of long-term planning. Two systems, which affect production and investments in the long run, were elaborated. They are the following:

- long-term investment policy which is connected to the regulation of purchase and distribution of fertilizers;

- the elaboration of a long-term system of economic regulators, which means fixing the system of taxation, and income redistribution, whereby partly production and partly environmental protection aspects are implemented and regulated by economic conditions.

The economy in Hungary is a centrally planned one and this means that investments which modify habitat conditions are financed by the state from centralized funds. The purchase and commercialization of fertilizers and plant protecting chemicals are also centrally managed. Basic raw materials such as phosphorus, potassium, and energy are imported. The level of production to a large extent depends on the supply of chemicals, which is financed by the state. This supply is managed jointly with other investment funds, which facilitates the choice of which policy should be followed in the long run.

Over the short term we augment the use of plant protecting chemicals and fertilizers at the expense of amelioration investments in order to obtain increased yields. Contrarily, the improvement of soil productivity is emphasized as a primary task, in which case a slower growth rate is achieved but the production conditions over the long term will be improved.

When making decisions to adopt a long-term investment policy, we not only fix the sum to be allocated to irrigation, amelioration, and the acquisition of chemicals, but we also decide on the transfer of investments. Investments are centrally funded but habitat conditions are improved locally, and therefore goods should be distributed in accordance with certain prerequisites of the structure of production.

There are five groups of plants in arable crop growth which cover more than three quarters the arable acreage; trends in yields are economically determined and their development differs according to the habitat. These five groups are: corn, cereals, protein feeds, oil seeds, and roughage. Investment goods should be regionally allocated according to the production level fixed for these groups of products in the diverse regions.

In this way, not only are annually available investment funds allocated to each region, but the quantity of the five main groups of products is also determined. In addition to centralized control of taxation and income, these regulations entail the elaboration of a system of subsidies. The application of such a system of subsidies in certain cases involves politically rather than economically justifiable considerations, for example, when development is increased to the desired rate in certain regions with bad environmental conditions, instead of investing the same amount of money to intensify production growth in a region with more favorable natural conditions. Within the farming in the respective regions, the selection of technologies and of environment-protecting agrotechnics can be influenced by these considerations. Thus the parameter system elaborated here determines the behavior of the system. Consequently, the sensibility and stability of the system must be investigated as a function of these parameters.

The following method can be recommended for elaborating the investment policy and the system of regulations. Taking the parameters elaborated at the supreme level of the model system and the actual environmental conditions into consideration, a system of regulations and a long-term investment policy should be formulated for a period of 15-20 years. These can be implemented at the regional level to help decide on the production structure. Since only a few parameters are dealt with at the planning level, the production specified in the optimization routine will diverge from the level of production assumed when the planning section was solved.

The effects of the investments and the regulations can be demonstrated only after a longer period, and therefore the deviation of the actual path from the planned path can be compared only after a certain period, for example, a quinquennial one. In cases where significant deviations are observed, then a new plan should be devised starting from the initial conditions characterizing the actual situation, and a new set of investment and regulation parameters elaborated. By this procedure feedback can be established from the production level to the planning level (see dotted lines in Figure 3).

The production process is described at the third level. The country is divided into regions and these regions are regarded as independent farming units. The conditions of small-scale farming are managed by the selection of appropriate technologies. Farming in these regions is described by separate models. Therefore, this part of the model system is called modeling at the regional level.

Models are not directly connected with each other at the regional level, so their production structures are independently set. In addition to the adoption of centrally formulated regulations, decisions are made based on rentability considerations. A production pattern suitable for meeting the country's needs should be developed. This pattern can be realized by setting minimum limits for the major groups of products.

When determining the production structure at the regional level, we consider the following parameters, i.e. groups of conditions:

a) territorial and land conditions;
b) biological conditions;
c) technological conditions;
d) product pattern regulations;
e) investment conditions;
f) economic conditions.

Here we briefly outline their role and the methods by which they are determined.

a) Territorial and land conditions. The acreage suitable for arable crop growth is described for each land type by means of territorial parameters (qualitative description). For each region we may distinguish between 10-15 soil types which are specified according to the natural conditions (soil, contours, etc.). The level of productivity can be increased by amelioration and irrigation measures, or reduced if inappropriate agrotechnics are applied. In each region there is a data bank of the quantitative and qualitative parameters of the different types of habitat. These parameters are used to fix the territorial limits of the production structure. After each production period the data bank should undergo revision so that the changes which have taken place as a result of land use and investments will be registered. In this way data is constantly updated for the coming year.

b) Biological conditions. Biological conditions can be divided into two groups:

- the increase in yields achieved as a consequence of genetic development;
- the rotation of crops influencing the continuity of production, which is regulated by well defined structures for diverse crops.

Yields obtained as a result of genetic development are determined according to land type. They do not appear in the model as constraints, but the level of fertilization and the selection of technologies to be applied, etc. are decided according to these yields.

As far as the rotation to be used in crop structure is concerned, only simple relations can be taken into account, such as those which maintain the desired crop structure and prevent the introduction of the monoculture system, or those that ensure adequate protection of hill country from serious erosion caused by insufficient vegetation. In the case where crops can only be produced at longer intervals, an appropriate structure will always be ensured if the acreage of the crops is kept below the limit of:

$$\frac{\text{available acreage}}{\text{number of years of rotation}}$$

c) Technological conditions. Technologies can be classified in two ways:

-- those used directly to obtain the desired production level;
-- those used indirectly to improve environmental conditions.

Technologies directly used for production include all machines and materials needed for soil cultivation, for plant care and for harvesting. When referring to a particular technological system in this paper, from now on we shall mean the set of machines used during the production period in the production of the respective crop - beginning with preparation of the soil and ending with the harvest - as characterized by their major parameters and the time requirements. Technological systems can be specified on the basis of the following criteria:

1) *Land size* - the size of the plot is measured according to the contiguous sowing acreage available for the chosen crop for which a system of technologies was elaborated. Larger contiguous plots exist in areas of flatland than in hill country. In each case, the technologies for small-scale farming are also determined.

2) *Desired yield and level of fertilization* - the potential yields on the diverse habitats are set according to genetic potential. The actual target yield aimed at in the respective areas depends on the level of fertilization and plant protection applied. We assume that the actual selection of technologies will cause neither an increase nor a reduction in yields.

3) *Environmental impacts* - we do not expect a direct increase or decrease in output as a result of technology selection, but we do expect long-term consequences as a result of technology application. The following impacts may prove harmful to the environment:

- serious erosion problems in hilly regions caused by the application of inappropriate technologies;
- changes in soil structure due to the use of heavy machinery;
- secondary salinization as a consequence of irrigation;
- too intensive fertilizer application causing negative soil modifications due to chemical reactions.

The negative impacts of technology application are registered for each production year in the data system describing habitat conditions. Deteriorating characteristics, in turn, result in lower potential yields. More appropriate technologies can be selected with reference to the machine pool available for the last production year and to new acquisitions. The number of machines available in the machine pool will decrease as machines become inoperable. In order to maintain the capacity of the machine pool, new acquisitions should constantly be used. We must expect deterioration of the environment in the long run not only as a result of direct economic considerations but also because of the application of new types of machinery.

Technologies selected for the improvement of environmental conditions, i.e. amelioration, should be dealt with separately from the technologies used in production. This has two reasons:

a) the technologies cannot be replaced by each other;
b) they are financed from different sources.

Amelioration investments are centrally financed by the state. Each year a region receives a certain sum which is to be spent on amelioration activities. This sum pays partly for the purchase of the required machines and materials, and partly for labor.

At the regional level investment expenditures are decided upon in the investment module. There is a condition that this fund be spent only on amelioration.

After a particular activity has been completed, the technology purchased may be used again and therefore it is advisable to keep the machine pool as a bank to be drawn upon for future amelioration activities.

Irrigation is also regarded as a form of amelioration. Only the construction of major irrigation works is centrally financed. Pumps, the construction of drainage and the watering clusters are regionally financed by the farms. Irrigation can only be carried out if this equipment is acquired or constructed.

Maintenance care and reconstruction work are equally important and are included in the technological data bank. Decisions concerning performance of the equipment are made at the regional level in the investment block.

d) Product pattern regulations - the production pattern in the regions is regulated directly only by the constraints on the major crops in the long run. The structure of the crops is specified by the regions based on considerations such as rentability. Rentability is of course, influenced directly by the regulations made, the price system, etc. which are presented at higher levels of the model system.

e) Investment conditions - investment funds are used for two purposes, namely:

- to carry out amelioration activities;
- to acquire new technologies.

As is already mentioned in point *c)*, according to the model, amelioration activities include the construction of irrigation works. This is both centrally (by the state) and regionally (by the farmers themselves) financed. Central funds cannot be spent on other improvements. However, decisions concerning the acquisition of new technologies are made regionally based on considerations such as rentability. The region also determines the rate at which to purchase new technologies and apply them, and adequate capital is accumulated from regional returns.

f) Economic conditions - no concrete economic conditions are formulated but each region is expected to maximize its profit. Taxes are included in the costs of production. The purchase of technologies for the maintenance of continuous production as well as the cost of repairing environmental damages should also be covered by the returns.

EXOGENOUS CONDITIONS

In the course of outlining the general model structure, we showed that the parameters which influence the operation of the system and upon which the system does not directly react, will be determined in the input part of the model. There are three such groups of parameters, i.e. those describing

- technological progress;
- genetic development;
- economic conditions (price systems, demand, export, investment goods, etc.).

Technological Progress

In 1978 a study entitled "The long-term technical-technological development of agriculture" was coordinated and funded by the OMFB (the State Office for Technical Development). The actual study was carried out by the Technical Institute of the MEM (the

Ministry for Food and Agriculture), which also published a description of detailed technological systems projected for the future. These volumes give a detailed forecast of development trends of production technologies and technical means up to the year 2000.

This forecast does not make provisions for revolutionary changes in the technologies of arable crop growth, but rather takes the further development of those methods currently applied into account. The expected introduction of new techniques which are known but not presently applied in Hungary is also taken into consideration.

With respect to the development of mechanization, the forecast considers mainly technics already being applied or those that have at least reached the implementation stage. It is assumed that by the year 2000 the introduction of results already obtained through research into practice at an ever increasing rate, will aid the development of a new generation of machines by the turn of the century. This new generation of machinery will be characterized by a qualitatively higher level of automation and will be adequately modified in their design.

The technological systems elaborated in the volumes covering the above study were regionally specific in nature, i.e. farm size and land contour and inclination were taken into consideration. The necessary labor force, machinery and materials required for operating the system are specifically described in the studies for 10 day periods. In addition to this system, the specification of a data bank enables the consideration of alternative technological systems which form a transition period from the present day to the year 2000. Technology systems thus elaborated form the basis of technology selection at the regional level.

Genetic Development

When determining the agro-ecological potential of agriculture, the expected yields of 13 arable crops for the year 2000 was forecasted by experts. This forecast was elaborated according to the following:

- 35 agro-ecological regions were distinguished according to climatic conditions and were treated as homogeneous units;
- 31 types of soil were distinguished which means that a total of 205 types of habitat could be specified;
- for each crop in each region 4 climatic types and their frequency were considered;
- environmental changes and the yield increasing effects of amelioration and irrgation were also taken into account.

In addition to the factors described above, the expected yield increases resulting from the genetic development of crops were considered.

Because we did not have a large number of parameters or knowledge about the relations existing between them, we could not undertake a forecast using merely mathematical means. We therefore took a joint approach. A yield forecast dependent on environmental conditions, i.e. on land types, was made based on both a written and verbal estimate by experts, and improved qualitatively by means of mathematical-statistical analyses. A control forecast was also predicted using econometric methods.

Here our task was not to forecast the yields expected for the year 2000 as a function of ecological factors, but rather to predict the trend of average national yields under certain assumptions, i.e. which rate of increase can we expect if we accept the forecast made by experts?

The basic hypothesis was that basically no new genetic or agro-technical findings which would influence production in a revolutionary manner would occur by the year 2000. Based on this hypothesis we could consider yield increases as being a process of saturation, since only the maximum exhaustion of existing resources could be calculated. For this purpose the production data of the past 80 years was available. According to our estimates increases in present output can be expected because of the better utilization of agro-ecological potentials and economic-technical conditions. We assume that the present potentials will be exhausted by the year 2000. We further assumed that this trend in increased yields for the period 1900 to 2000 would be shown by a symmetrical logistic curve.

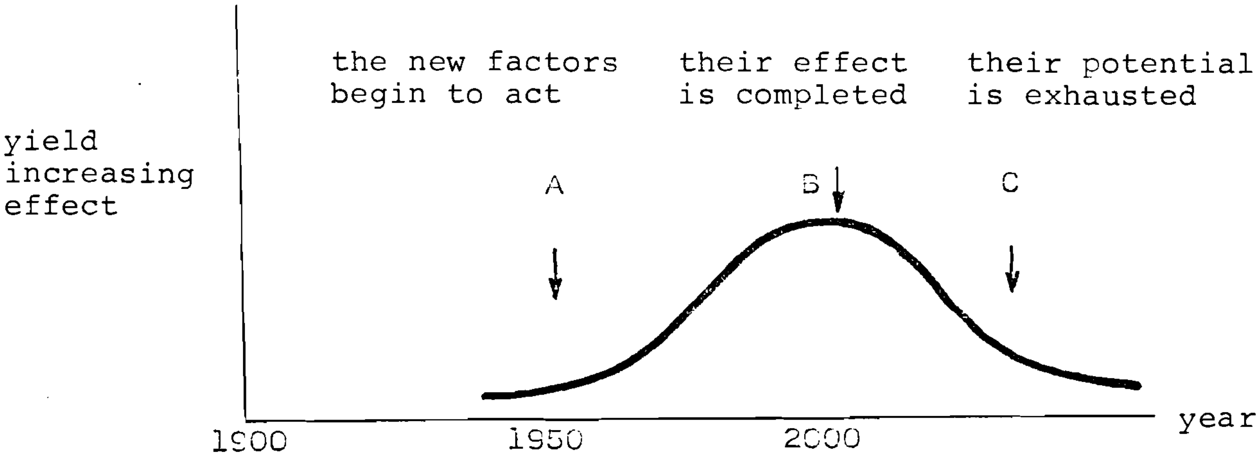
In the case of major crops - i.e. corn and wheat - the national average yields forecasted by experts and the values calculated by econometric methods were very similar. Yield curves for the yields expected at the turn of the century (from the year 2000 to 2010) were also set. These curves may be said to represent genetic development. In the same way as average national yields for the year 2000 were assessed from the yields of mosaics, the yields which can be achieved in the diverse habitats in the period up to the year 2000 can be calculated. These will be considered as the basic level of productivity in the respective habitats. We shall outline this process in detail when describing the production forecast block of the model at the regional level.

A brief summary of the methodology applied to estimate the yield curves follows. The data used in the calculations were the respective time series of Hungarian and international yields between 1901 and 1977. We assumed that:

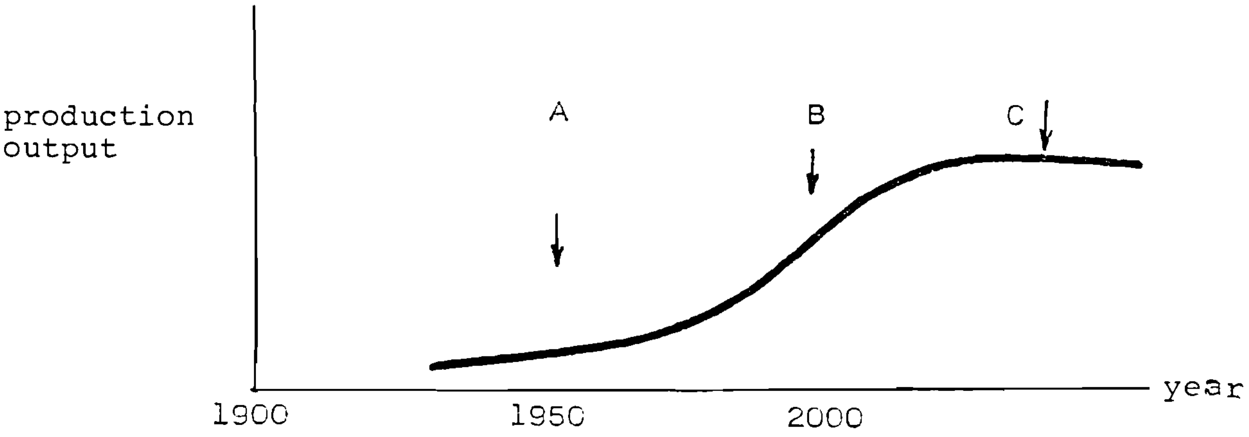
a) the domestic trend of yields will progress in a similar way to that in countries with a developed agriculture and natural conditions similar to those prevailing in Hungary. Thus international data can be used to check domestic results.

b) according to the evaluation of our data, yields did not increase at all or did so only to a minimum extent in the period from 1900 to 1950. Increases in yields for the period following until the year 2000 will occur as a result of those factors whose influence has gradually been felt since the 50's and the 60's. These factors (large-scale farming, intensive farming, those farms using modern agrotechnics, natural conditions, improved use of genetic potential of those varieties already existing, etc.) are already prevalent in some cases; they vary in extent; some of them have an effect only at the experimental level or only in the most advanced farms, whereas others have the same effect over a wider range (several places at once). The further improvement of current results can only be expected if these factors are introduced into practice, propagated or if ecological conditions are better utilized. We assume that these factors will remain in use until about the year 2000, i.e. when new factors (new varieties, new agrotechnics) will be needed to achieve further similar increases. Since we do not consider such new factors at present, our results (in accordance with our conditions) will not indicate any increase after the year 2000.

Our assumptions can be illustrated in the following way:

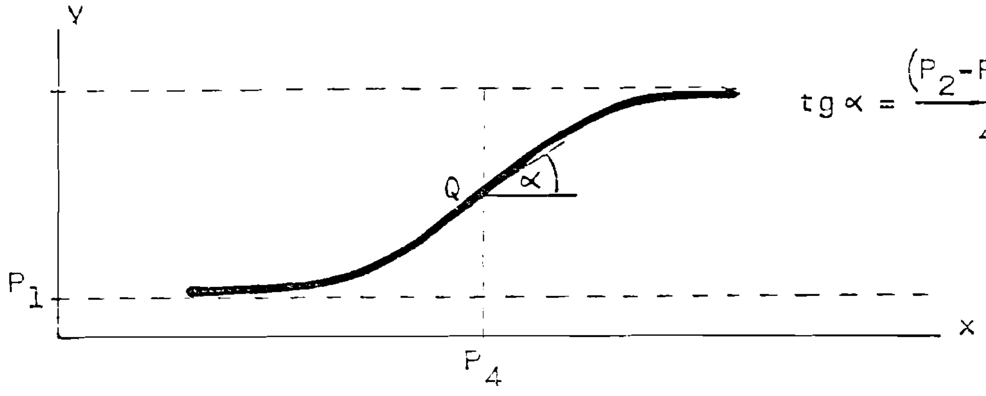


The corresponding yield curve is demonstrated by the following figure:



For calculations we used the following symmetrical logistic function:

$$y = P_1 + \frac{P_2 - P_1}{1+e^{-P_3(x-P_4)}}$$



$$\mathrm{tg}\,\alpha = \frac{(P_2-P_1)\,P_3}{4}$$

The parameters p_1, p_2, p_3, p_4 which figured in the formula were to be fixed or interpreted.

p_1 - level in the period preceding the increase (which was read from data of earlier years);

p_2 - level to be reached at the end of the development period (related to experts' estimates);

p_3 - proportionate to the maximum rate of increase (being the object of the experts' estimation);

p_4 - the period when the rate of increase, i.e. annual growth, is fastest (object of expert judgement);

As referred to by the attributive "symmetrical", the curve is summetrical at point Q, which means that starting with zero increase, the rate of growth increases to a maximum value and then begins to decrease in a similar way but in the reverse direction.

We demonstrate, for example, the path of increase for wheat yield. We may treat the unconstrained curve as a forecast, and in this case we did not apply an restrictions on yields to be achieved by the turn of the century. In the other three cases, the time series of the yields were completed for the period

$t \in (2001, 2010)$ using the results obtained from the experts' forecast. In this way the value p_2 was indirectly determined. (See Figure 4.)

Economic Conditions

Those economic parameters, conditions, which are

- -- used during the course of the entire period investigated and
- -- are exogeneous to the system

are indicated at the input level. These parameters can be grouped into the following classes:

a) the price system;
b) the trend of state investments available for agriculture;
c) the forecast on domestic consumption;
d) the export-import possibilities.

It may appear strange that the elaboration of domestic consumption and the price system are treated separately from the production sector, but this can be explained as a consequence of changes taking place exogenously (energy prices, etc.) because no reliable price forecasts can be elaborated.
This situation is expected to prevail also in the future.

The purchase price of machinery and materials, as well as the implementation costs of investments, are to a great extent determined by the production of the nonagricultural sectors, by the import prices, etc. For this reason no acceptable price system can be worked out in an open economy, even in cases where the production and consumption of the other sectors are also taken into account.

For the above-mentioned reasons the following solution is conceived: taking diverse assumptions, and international forecasts into consideration, we work out time series for the price of energy, fertilizers and the acquisition of technologies, which replace the price system for the major elements exerting the greatest influence on production, especially in cases where investment costs and production prices are determined.

Government investments include:

- -- the financing of amelioration activities;
- -- the construction of irrigation works, and
- -- the supply of fertilizers to cover the needs of the whole country.

In fact only amelioration activities and the construction of irrigation works can be considered as investments. Basic energy materials and fertilizers are practically all imported. The production and commercialization of fertilizers is monopolized by the state. Because of purchase and production, the level of fertilizing must be planned ahead, and no significant changes occur from year to year in this respect. When outlining the

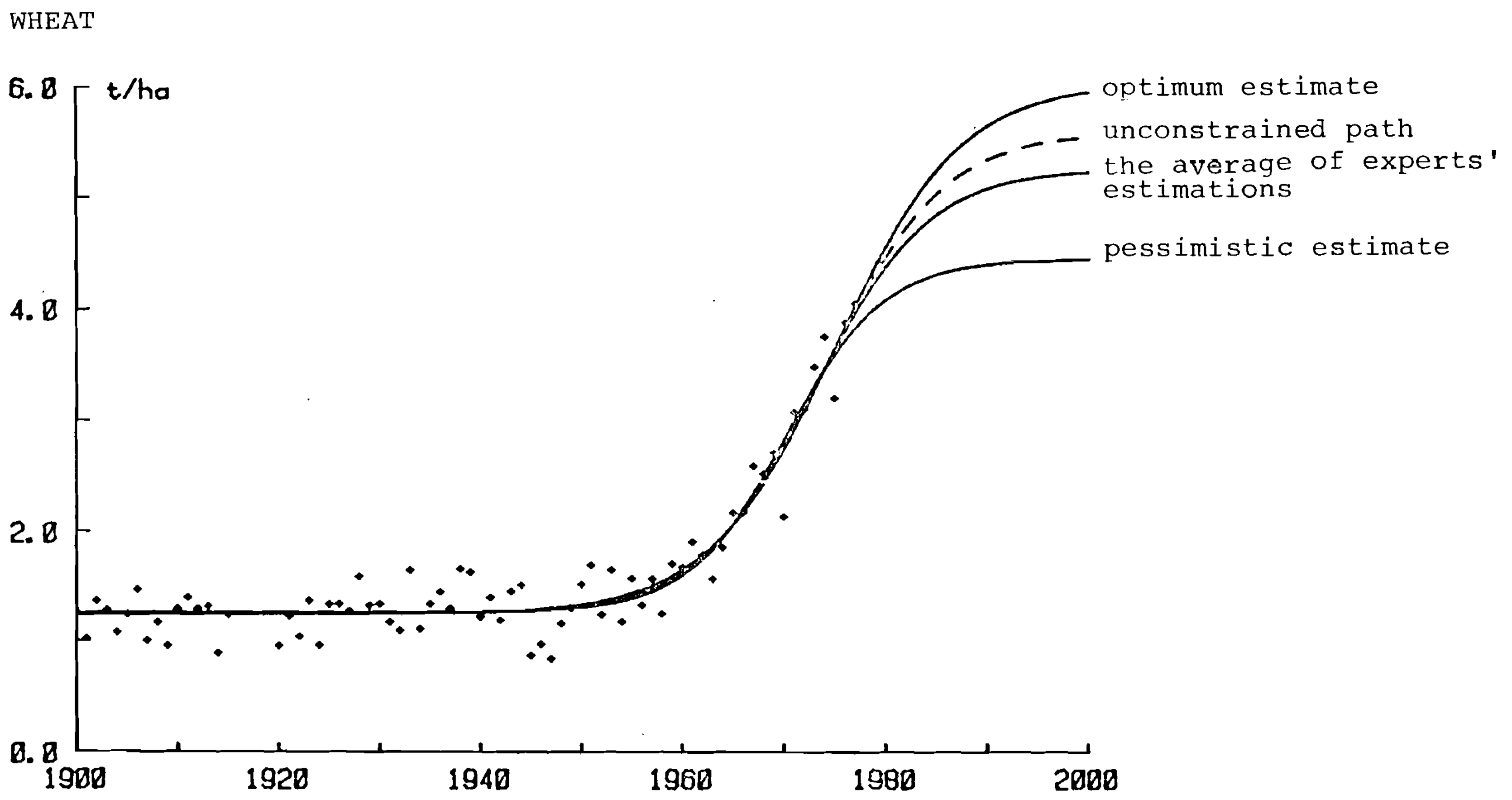


Figure 4. Projected paths of wheat yield in Hungary.

structure of the general model system, we decided to treat the three factors jointly. It must be stressed, however, that the "investment" funds spent on the production and purchase of fertilizers are similarly paid for, as are other direct inputs into production.

That part of amelioration investments and construction of irrigation works financed by the state will not be directly covered by the farms. We assume that no modifications will be made in this practice in the future.

The withdrawal of a certain part of the additional income which came into existence as a consequence of improved land conditions, created by regional resources will be taken into account when the system of government regulations is specified. A central investment fund will be developed after data for the long-term plan and diverse forecasts have been considered.

In recent years several forecasts have been estimated with respect to trends in domestic consumption. The forecasts differ respectively because consumption according to different kinds of diet is also accounted for.

We propose to take three variants into consideration for this work. They are as follows: consumption variants which correspond to present domestic dietary habits, reflect present Western-European standards, and which can be considered as optimum for nutrition. A consumption system describing the these three variants in detail is available in the study carried out on the agro-ecological potential (Harnos, 1982).

Forecasts of the probable, expected export-import potentials pose an almost insolvable task in the changing world of today. A considerable part of Hungarian agricultural produce is already being exported in the present day, and the rate of export will increase parallel to increases in production.

Taking this fact into consideration, we are considering the elaboration of several diverse export-import structures which incidentally correspond to extreme variants, and which also have the purpose of enabling us to investigate problems such as: how we should prepare ourselves for such changes, and which production structure is the least sensitive to the most diverse changes.

The forecasts made by the Hungarian Agricultural Model (HAM) will also figure as one of the variants.

The Planning Level

The solution of a twofold problem is envisaged at this level of the model system, namely:

-- the specification of the actual values of the parameters for the regions and sectors; and

-- the elaboration of a long-term plan and a system of income controls to be used on the regional level as constraints of the production module.

Regional production is determined on the basis of one year plans by maximizing the net income. The information contained in the plans and controls is used to enhance the development of agriculture according to long-term goals.

The determination of the actual values of the parameters and the establishment of an investment policy and of income controls provide for the linkage of regions and ensures an equilibrium. A two way connection between the regional and the planning level puts central plans into practice.

Investment Policy

Long-term investment policy is described by a control problem with different investment decisions and land use constituting the set of controls. The amount of available land in certain quality classes represents the state of the system.

State Variables

Centrally financed agricultural investments are allocated to regions and investment types in each time period. The relatively large regions were delineated according to natural geography and agroecological characteristics. These regions are the same large regions dealt with in the Survey of the Agroecological Potential project. The borders of these regions were modified to correspond to administrative boundaries in order to make the data collection easier. As far as the natural characteristics of the regions are concerned, we consider them homogeneous. Differences between them are well reflected in the characteristic practice of land use. The number of regions considered in the model is 7 and this may be decreased to 4. The state variables represent the quality of land in the region changing over time. The time horizon is T years, the time of the initial period is denoted by $t = 0$. Let $x_k(0)$ denote the area of the presently cultivated land in the k-th region.

$$x_k(0) = x_{kj}(0) + x_{km}(0) + x_{k\ell}(0) + x_{kr}(0)$$

The meaning of the variables on the right hand side is as follows:

- x_{kr} is the amount of land with low productivity. A part of it can be improved by carrying out the necessary land reclamation. On the other part, reclamation is impossible or uneconomical.

- x_{kj} is the amount of land with productivity that can be improved by land reclamation or that can be decreased by applying inappropriate technology.
- x_{km} is the amount of land with high productivity that cannot be increased further by land reclamation. Its value, i.e. the area can be increased by carrying out the necessary reclamation works on land of the previous classes.
- $x_{k\ell}$ is the amount of irrigated land; irrigation takes place only on reclaimed land.

In the t-th year we have

$$x_k(t) = x_{kj}(t) + x_{km}(t) + x_{k\ell}(t) + x_{kt}(t) \qquad t \in \{1,2,\ldots,T\} \tag{1}$$

The state of the system is constrained by natural limitations, and governed by the land use and the investment policy. The main relationships considered are as follows:

(a) The area of land of low productivity is bounded from below by the non-reclaimable land:

$$x^0_{kr} \leq x_{kr}(t) \qquad t \in \{1,2,\ldots,T\} \tag{2}$$

(b) The area of irrigated land is limited by the available irrigation water, the existing irrigation infrastructure and other factors:

$$x_{k\ell}(t) \leq x^0_{k\ell} \qquad t \in \{1,2,\ldots,T\} \tag{3}$$

It should be mentioned here that, on this level of the model, only the construction, maintenance and reconstruction of the main irrigation works are considered. Their operation is the responsibility of the farmers at the regional level. Part of the irrigation investments is to be used for maintenance, whereas the rest is for the construction of new irrigation works. Maintenance expenses are only considered after a few years.

According to our hypostheses, irrigation production takes place only on the best land, and this means that if irrigation is given up in some place, land in the class m increases. We also suppose that on irrigated high quality land no deterioration will occur unless conditions of irrigation are prevalent.

(c) Class m consists of non-irrigated land of good quality in a good state. The land quality cannot be increased further, but if the necessary maintenance is not carried out, it deteriorates in 2 stages. Deterioration leads to the transfer of land to class j in the first step and to class r in the second.

(d) The land in class j is of average quality, subject to improvement or deterioration, and it can be subsequently transferred to class m or r respectively.

The possible transfers and hypotheses concerning the classes are the following:

i) in the case of deterioration, in the series

$$x_{k\ell} \rightarrow x_{km} \rightarrow x_{kj} \rightarrow x_{kr}$$

Each step must be taken sequentially.

ii) Irrigation can be introduced only to land suitable for irrigation.

iii) In addition to the immediate transfers

$$x_{k\ell} \leftarrow x_{km} \leftarrow x_{kj} \leftarrow x_{kr}$$

the change

$$x_{km} \leftarrow x_{kr}$$

is also possible, although it requires a higher amount of investments.

Control Variables

We consider two types of control variables in the model:

- -- investments
- -- land use.

Investment variables are divided into four groups:

- -- the import and production of fertilizers
- -- amelioration investments
- -- the construction of irrigation works
- -- the maintenance of irrigation works.

These four groups are handled as sectors in sequence. The available resources should be divided between the regions and the sectors.

Constraints on investments are formulated as a system of linear inequalities, and can be described in concise form as follows

$$B\,\underline{u}(t) \leq \beta(t) \qquad t \in \{1,2,\ldots,T\} \qquad (4)$$

$$\underline{u}(t) \geq \underline{0}$$

The vector $\underline{u}(t)$ is of the following form, consisting of the available investments in the k-th region and in investment type i:

$$\underline{u}(t) = \{u_{ki}(t)\}$$

where

- i = 1 stands for fertilizers,
- i = 2 for amelioration,
- i = 3 for the construction and
- i = 4 the maintenance of irrigation works.

Changes in the price level of individual investment types are given by the functions

$$f_i(t) \qquad i \in \{1,2,3,4\} \qquad (5)$$

In more detailed form, equation (4) means, among other things, the following inequalities:

$$\sum_k \sum_i u_{ki}(t) \leq b(t)$$

$$b^s_{i1}(t) \leq \sum_k u_{ki}(t) \leq b^s_{i2}(t) \qquad i \in \{1,2,3,4\} \qquad (6)$$

$$b^r_{k1}(t) \leq \sum_i u_{ki}(t) \leq b^r_{k2}(t)\ , \qquad k \in \{1,2,\ldots,K\}$$

Here $b(t)$ is the total amount of investments available in the year t to be determined on the input level. The second and third rows under (6) represent possible constraints on the distribution of investment resources. An appropriate investment policy can be determined by the step by step extension of the system (6). The effects of investments on the quality of the land will be considered later.

Land Use and Fertilization

The difference between the land classes is represented by the yield which can be achieved by applying "average" technologies. The Survey of the Agroecological Potential (SAP) contains detailed prognoses of this potential yield. Our model deals with the following reference crops:

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

Based on the above-mentioned forecasts, we developed yield trajectories, allowing us to determine the expected potential yields in each region, for each soil class and each crop, for each year, which was denoted by

$$y_{ksnp}(t)$$

Here k means the region, n the crop, t the time and s the soil type. This means that s takes the values r, j, m or ℓ. The yields are then decreased or increased according to the intensity of fertilizer application. The yields corresponding to the different fertilization levels are denoted by

$$y_{ksnp}(t) \qquad p \in \{1,2,\ldots,P\}$$

where p is the number of the fertilizer levels considered. The amount of fertilizer required for achieving a yield of $y_{ksnp}(t)$ is denoted by

$$\alpha_{ksnp}(t) = \hat{\alpha}_{ksnp} \cdot \xi(t) \qquad (7)$$

Here $\hat{\alpha}_{ksnp}$ is the presently required amount of fertilizer and $\xi(t)$ represents the increasing fertilizer requirements due to higher yields.

Let $z_{ksnp}(t)$ denote the area of land used for the production of the crop n in region k, under soil class s, with fertilizer level p in year t. The amount of fertilizer to be used in the k-th region is constrained in the following way:

$$\sum_s \sum_n \sum_p \alpha_{ksnp}(t) \cdot z_{ksnp}(t) \leq \frac{u_{kl}(t)}{f_l(t)} \qquad (8)$$

Here $f_l(t)$ represents the changes in the price level of fertilizers over time.

As far as land is concerned, the following inequality obviously holds:

$$\sum_n \sum_p z_{ksnp(t)} \leq x_{ks}(t) \qquad t \in \{1,2,\ldots,T\} \qquad (9)$$

The rest of the constraints can be divided into two groups:

- -- biological limitations on the production structure ensuring the crop rotation required by continuous production,
- -- upper and lower bounds of production.

This can be described by the following system of inequalities:

$$\begin{aligned} &D\,\underline{z}(t) \leq \underline{h}(t) \\ & \qquad\qquad\qquad\qquad t \in \{1,2,\ldots,T\} \qquad (10) \\ &\underline{z}(t) \geq \underline{0} \end{aligned}$$

The vector $\underline{z}(t)$ is of the following form:

$$\underline{z}(t) = \{z_{ksnp}(t)\}_{ksnp}$$

To sum up (8), (9), and (10), the constraints on land use and fertilization can be formulated in the following concise form:

$$\begin{aligned} D\,\underline{z}(t) &\leq \underline{h}(t) \\ D_1\underline{z}(t) &\leq \underline{x}(t) \\ D_2\underline{z}(t) &\leq D_3(t)\ \underline{u}(t) \\ \underline{z}(t) &\geq \underline{0} \end{aligned} \qquad (11)$$

The Effects of Investments and Land Use

After having described the investment and land use variables controling the functioning of the system, we now turn to the relationships between the control variables and the state transitions.

Land use, i.e. agricultural activity leads in many cases to the deterioration of the quality of the environment.

Improvements in productivity can be reached by

-- amelioration,
-- construction and
-- reconstruction of irrigation works.

The Effects of Land Use

The effects which land use has on land quality are represented by changes in soil class. This is done in such a way that an amount of land is transferred to a lower (in special cases, e.g. pastures, to a higher) class. The amount transferred is determined by the expected decrease (in cases, increase) of the yield.

Let us give a simple example, where in year t, we have only one activity on an area of z_{ks} which leads to $\eta \cdot 100\%$ decrease in yield. Let the expected yield be equal to y_{ks} and y_{ks-1} in soil class s and s-1, respectively. Then we have

$$x_{ks-1}\ (t+1) = x_{ks-1}(t) + \frac{\eta \cdot y_{ks}(t)}{y_{ks}(t) - y_{ks-1}(t)} \cdot z_{ks}(t)$$

and

$$x_{ks}\ (t+1) = x_{ks}(t) - \frac{\eta \cdot y_{ks}(t)}{y_{ks}(t) - y_{ks-1np}(t)}\ z_{ks}(t)$$

We used the following notation:

$$s - 1 = \begin{cases} r & \text{if } s=j \\ j & \text{if } s=m \end{cases}$$

In the case of s=r, no deterioration is considered.

The actual relationships used in the model are:

$$x_{ks-1}(t + 1) = x_{ks-1}(t) + \sum_{n,p} \frac{\eta_{ksnp}(t) \cdot y_{ksnp}(t)}{y_{ksnp}(t) - y_{ks-1np}(t)} \cdot z_{ksnp}(t)$$

$$x_{ks}(t + 1) = x_{ks}(t) - \sum_{n,p} \frac{\eta_{ksnp}(t) \cdot y_{ksnp}(t)}{y_{ksnp}(t) - y_{ks-1np}(t)} z_{ksnp}(t) \qquad (12)$$

$$s-1 = \begin{cases} r & \text{if } s=j \\ j & \text{if } s=m \end{cases}$$

Amelioration

The above described relationships correspond only to changes in one direction. Changes in the other direction, i.e. the improvement of the quality of the environment are controlled by investments. Two types of investment are considered, namely, a) amelioration, and b) irrigation.

The amelioration carried out in the t-th year comes to effect in the t + 1 - st. The realization of hydrological amelioration in a larger area, or the introduction of irrigation require a large amount of investments over a longer period of time.

Let β_{ks} denote the capital required for the amelioration of the s-th soil class in region k which is counted in fixed prices, and $f_2(t)$ the forecasted price changes. This means that in year t the investment requirements are

$$f_2(t) \cdot \beta_{ks}$$

in Forint/ha. Further let $u_{k2}(t)$ denote the available capital for ameliorative investemtns and $v_{ks}(t)$ denote the amount of ameliorated land of soil type s in region k. In this case, amelioration is limited by the following inequality:

$$f_2(t) \sum_s \beta_{ks} \cdot v_{ks}(t) \leq u_{k2}(t) \qquad (13)$$

The changes in soil class due to amelioration and land use are described by

$$x_{km}(t + 1) = [A\ \underline{z}(t)]_{km} + v_{kr}(t) + v_{kj}(t)$$

$$x_{kr}(t + 1) = [A\ \underline{z}(t)]_{kr} - v_{kr}(t)$$

$$x_{kj}(t + 1) = [A\ \underline{z}(t)]_{kj} - v_{kj}(t)$$

$$x_{kl}(t + 1) = x_{kl}(t)$$

Here, the matrix A represents the relationship (12).

The Construction of Irrigation Works

Both types of irrigation investment are described by discrete variables. This is explained by the fact that the investment requirement of an irrigation works is large and the construction work cannot be carried out in one year; further, irrigation can only be begun if the entire canal system of the area is ready. Similarly, if maintenance work is not carried out for a longer period, irrigation becomes impossible at the same time for the whole region.

Let

γ^{+}_{ki} denote the present investment costs of the i-th irrigation work in the k-th region,

$i \in I_k = \{1,2,\dots,i_k\}$

$f_3(t)$ denote the forecasted price changes affecting the cost of irrigation works, and

w^{+}_{ki} denote the area gained for irrigated cultivation after the realization of the i-th irrigation work.

The order of the i-s also represents the order of importance of the irrigation investments.

The amount of investments available for the construction of new irrigation works is $u_{k3}(t)$ and for their maintenance is $u_{k4}(t)$. The relationship which describes possible irrigation is as follows. Irrigated cultivation on the area w^{+}_{k1}, i.e. the most important area, can be started when

$$\sum_{s=1}^{t} u_{k3}(s) \frac{1}{f_3(s)} \geq \gamma_{k1}^{+} ,$$

the area w_{k2}^{+} (i.e. the second most important area) can be irrigated when

$$\sum_{s=1}^{t} u_{k3}(s) \frac{1}{f_3(s)} \geq \gamma_{k1}^{+} + \gamma_{k2}^{+} ,$$

and so on. This can be formulated by the use of the discrete, 0,1 valued variables $\varepsilon_{ki}^{+}(t)$, $i \in I_k$. We suppose that

$$\varepsilon_{ki}^{+}(1) \leq \varepsilon_{ki}^{+}(2) \leq \cdots \leq \varepsilon_{ki}(T)$$

and

$$\varepsilon_{ki}^{+}(t) \geq \varepsilon_{ki+1}(t)$$

if $i, i+1 \in I_k$.

Let us first consider a special case, i.e. the conditions for the realization of the first new irrigation work. The next two inequalities ensure that $\varepsilon_{k1}^{+}(t) = 0$ until the total amount of available investments in fixed prices is less than γ_{k1}^{+} and $\varepsilon_{k1}^{+}(t) = 1$ if it is greater or equal.

$$\sum_{s=1}^{t} \frac{u_{k3}(s)}{f_3(s)} - \varepsilon_{k1}^{+}(t) \cdot \gamma_{k1}^{+} \geq 0$$

$$\frac{1}{\sum_{t=1}^{t} b(t)} \left(\sum_{s=1}^{t} \frac{u_{k3}(s)}{f_3(s)} - \gamma_{k1}^{+} \right) < \varepsilon_{k1}^{+}(t) \tag{14}$$

for all $t \in \{1,2,...T\}$.

The same conditions are required in the general case:

$$\sum_{s=1}^{t} \frac{u_{k3}(s)}{f_3(s)} - \varepsilon_{kj}^{+}(t) \cdot \sum_{i=1}^{j} \gamma_{ki}^{+} \geq 0 \tag{15}$$

$$\frac{1}{\sum_{t=1}^{T} b(t)} \left(\sum_{s=1}^{t} \frac{u_{k3}(s)}{f3(s)} - \sum_{i=1}^{j} \gamma_{ki}^{+} \right) < \varepsilon_{kj}^{+}(t) \qquad (16)$$

for all

$$t \in \{1,2,\ldots T\} \qquad \text{and} \qquad j \in \{1,2,\ldots,i_k\} \quad .$$

The Reconstruction of Irrigation Works

We hypothesize that:

-- new irrigation works need no reconstruction in the period considered

-- reconstructed works need no further reconstruction

-- in cases where the necessary reconstruction is not carried out in time, the area ceases to be irrigable.

Let $w_{ki}^{-}(t)$, $i \in J_k = \{1,2,\ldots,j_k\}$ denote the irrigable areas of existing irrigation works. The index i also represents the order of reconstruction, and τ_{ki} denotes the year by which the i-th reconstruction should be completed. Here $\tau_{k1} < \tau_{k2} <, \ldots, < \tau_{kjk}$, and

γ_{ki}^{-} denotes the cost of reconstruction. We describe reconstruction in the following way. Irrigable land decreases by w_{ik}^{-} in the year $\tau_{ki} + 1$. If reconstruction is completed by this time, the area of land increased is the same, i.e. the irrigable area does not change. In order to formalize this, we introduce the discrete and 0,1 valued variables $\varepsilon_{kj}^{-}(t)$.

Let

$$\varepsilon_{kj}^{-}(t) \leq \varepsilon_{kj}^{-}(t+1)$$

$$\varepsilon_{kj}^{-}(t) = 0 \text{ if } t < \tau_j \text{ and}$$

$$\varepsilon_{kj}^{-}(t) \geq \varepsilon_{kj+1}^{-}(t) \qquad (17)$$

To determine the $\varepsilon^{-}_{kj}(t)$ - s we have:

$$\frac{\sum_{s=1}^{t} \frac{u_{k4}(s)}{f_4\ (s)}}{\sum_{i=1}^{j} \gamma^{-}_{k,i}} - 1 \leq \varepsilon^{-}_{kj}(t) \tag{18}$$

and

$$\sum_{s=1}^{t} \frac{u_{k4}(s)}{f_4\ (s)} - \sum_{i=1}^{j_n} \gamma^{-}_{ki} \cdot \varepsilon^{-}_{ki}(t) \geq 0 \tag{19}$$

The effects of irrigation (construction and reconstruction) can now be added to those of land use and amelioration, as follows:

$$x_{kr}(t + 1) = [Az(t)]_{k_r} - v_{k_r}(t)$$

$$x_{kj}(t + 1) = [Az(t)]_{kj} - v_{kj}(t)$$

$$x_{km}(t + 1) = [Az(t)]_{km} + v_{kj}(t) + v_{k_r}(t)$$

$$- \sum_{i=1}^{i_k} \varepsilon^{+}_{ki} \cdot w^{+}_{ki} - \sum_{i=1}^{j_k} [\xi_{ki}(t) - \varepsilon^{-}_{ki}(t) \cdot w^{-}_{ki}$$

$$x_{k1}(t + 1) = x_{k1}(t) + \sum_{i=1}^{i_k} \varepsilon^{+}_{ki} \cdot w^{+}_{ki}$$

$$+ \sum_{i=1}^{j_k} [\xi_{ki}(t) - \varepsilon^{-}_{ki}(t)] \cdot w^{-}_{ki} \tag{20}$$

Here

$$\xi_{ki}(t) = \begin{cases} 0 \text{ if } t \leq \tau_i \\ 1 \text{ if } t > t_i \end{cases}$$

Summary

Using matrices and considering all the factors, we can now set up the equation governing the state of the system:

$$\underline{x}(t+1) = A(t)\underline{z}(t) + B(t)\underline{v}(t) + C(t)\underline{\varepsilon}(t) \qquad t \in \{1,2,\ldots T\} \tag{21}$$

where the vector

$\underline{z}(t)$ = land use

$\underline{v}(t)$ = ameliorated land

$\underline{\varepsilon}(t)$ represents irrigation .

The matrices A, B and C express their respective influences on the quality of the land.

The limitations set up in (2) and (3) are of the form:

$$\underline{x}_o \leq \underline{x}(t) \leq \underline{x}_\infty \qquad t \in \{1,2,\ldots,T\} \tag{22}$$

The inequalities under (13) can be written as:

$$R(t)\ \underline{v}(t) \leq \underline{u}(t) \qquad t \in \{1,2,\ldots,T\} \tag{23}$$

The relationship governing irrigation investments has the form:

$$T \cdot \underline{\varepsilon}(t) \leq L(t)\ \underline{u}(t)$$

$$\underline{0} \leq \underline{\varepsilon}(t) \leq \underline{\varepsilon}(t+1) \leq \underline{\varepsilon}_o \tag{24}$$

Optimality

After considering the constraints of the system and the relationship determining its dynamics, let us turn to the problem of optimality. There are a number of possibilities, a few of which we list below for investigation.

- -- The maximization of total production in the last time period or in some aggregated periods or in the whole of the time period under investigation. From a methodological point of view, the three versions are similar and constitute the maximization of a linear goal function. In such a case the model can easily be transformed into a mixed (real-integer) linear programming problem.
- -- Another possibility is the control of production and land use in such a way that one or more characteristics follow certain prescribed reference curves.

The solution to the following problem seems to be possible. Let $Y^o(t)$ denote the genetic prognosis of the n-th crop and $Y_n(\underline{z},t)$ denote the yield corresponding to land use in $\underline{z}(t)^n$.

Then

$$Y_n(\underline{z},t) = \frac{\sum_k \sum_s \sum_p y_{knsp}(t)\ z_{knsp}(t)}{\sum_k \sum_s \sum_p z_{ksnp}(t)}$$

Although Y_n depends directly on $\underline{z}$ alone, we can see that, at an earlier stage, it in fact depends implicitly on the rest of the state and control variables as well. We would like to prevent the actual yields from falling below the values given by the genetic prognosis. This can be controled by setting additional linear constraints,

$$Y_n^o(t)(1 - \delta_n) \sum_k \sum_s \sum_p z_{ksnp}(t) \leq \sum_k \sum_s \sum_p y_{ksnp}(t)\ z_{ksnp}(t)$$

$$n \in \{1,2,\ldots N\}$$
$$n \in \{1,2,\ldots T\} \qquad (25)$$

and by formulating a goal function which would make the yields rise above the reference curve to the greatest possible extent as frequently as possible.

Here, the n-th goal function is given in the formula

$$\phi_n(z) = \sum_{t=1}^{T} [Y_n^o(t) - Y_n(\underline{z},t)] \qquad (26)$$

which is to be maximized. The function ϕ_n is non-linear; it is a quotient of two linear functions for each t. Optimal structures which we would have for the individual values of n would define situations in which the production of the n-th crop is preferable. To avoid this phenomenon, it is necessary to consider the N different goal functions together, i.e. to consider a <u>multi-objective optimization problem</u>.

A number of different compromise solutions could be produced. One of the most convenient would be to use the utopia point as a reference, and then to minimize the convex combination of the differences of the coordinates. This means the solution to the problem.

$$\max_{(\underline{u},\underline{x},\underline{z})} \{\phi_n ('\underline{z}) : (\underline{u},\underline{z},\underline{x}) \in \Omega \} = \phi_n^*$$

for all $n \in \{1,2,...N\}$ where Ω is the set of the feasible controls and of the states corresponding to them. This is followed by the minimization of the function

$$\phi_{\underline{\lambda}}(t) = \sum_{i=1}^{N} \lambda_i \{\phi_i^* - \phi_i(\underline{z})\}$$

on the set Ω . The weight vector $\underline{\lambda} = (\lambda_1,...\lambda_N)$ with $\lambda_n \geq 0$, $\sum_{i=1}^{N} \lambda_i = 1$ is exogeneously given with the weights reflecting the importance of the respective crops.

The problem outlined above is difficult to solve because of the nonlinearity of the goal function. The problem can be made easier to handle by substituting the functions ϕ_n for the average yields for the whole period. If we denote this function by ψ_n, it has the following form:

$$\psi_n(\underline{z}) = \frac{\sum\limits_t \sum\limits_k \sum\limits_s \sum\limits_p y_{ksnp}(t)\ z_{ksnp}(t)}{\sum\limits_t \sum\limits_k \sum\limits_s \sum\limits_p z_{ksnp}(t)}$$

In this case, the problem

$$\max \{\psi_n(\underline{z}) : (\underline{u},\underline{z},\underline{x}) \in \Omega \}$$

is a mixed (real-integer) hyperbolic programming problem that can be transformed into a mixed linear problem. Computational experiments using the multiobjective optimization program developed at IIASA and the MINOS package are under way.

A third possibility is the following solution which is the most difficult of all from a technical point of view.

The same curves $Y_n^o(t)$ are used for reference and the fulfilment of equation (25) is required. The deviation of the national yields from the reference curve is measured by the goal function in the following form:

$$\chi_n(z) = \sum_{t=1}^{T} \Phi_n^+(t)\ [Y_n^o(t) - Y_n(\underline{z},t)]_+ + \sum_{t=1}^{T} \Phi_n^-(t)\ [Y_n^o(t) - Y_n(\underline{z},t)]_-$$

The notations $[\ \ ]_+$ and $[\ \ ]_-$ stand for the positive and negative parts of the expressions in the brackets. The weight functions $\Phi_n^+(t)$ and $\Phi_n^-(t)$ are exogeneously given. The goal is to maximize the function $\chi_n(z)$, i.e.

$$\max \{\chi_n(z) : (\underline{u},\underline{z},\underline{x}) \in \Omega \}$$

To avoid an unbalanced development, we should consider a multiobjective problem instead of searching for the optima in case of the individual n-s. Of course, the function $\chi_n(z)$ is non-linear.

Regional Level

The relationship between technology, production and the environment are analyzed in the regional model in a relatively detailed way. Production structure is determined on a year by year basis considering

- economic conditions
- production quotas
- quantitative and qualitative limitations of the land
- available technologies
- land use constraints ensuring continuous production determined on a biological basis.

The parameters of the first two groups of constraints are given by the input or the planning level.

Changes in the quality of the habitat are a function of the environmental effects of agricultural activity. The deterioration resulting from the technology applied and improvements made as a result of investments are determined each year. Investments are allocated in the regional investment model. The available set of technologies is also revised from year to year according to depreciation and the purchase of new equipment. Land use constraints which ensure the continuity of production are derived from the crop rotation patterns in practice. These are considered constant over the whole period considered.

Development at the regional level is compared with figures at the planning level. If necessary, long-term plans or income controls are then modified. The structure of the regional model in shown in Figure 5.

Models of similar structure are built for each region. These models work independently of each other. In the detailed description of the models, references to individual regions are omitted for the sake of simplicity.

The Regional Production Model

Production structure is described by a real-integer linear programming problem. Constraints can be grouped according to the following:

- area constraints
- constraints on land use
- constraints on production
- technological constraints
- economic conditions.

Area Constraints

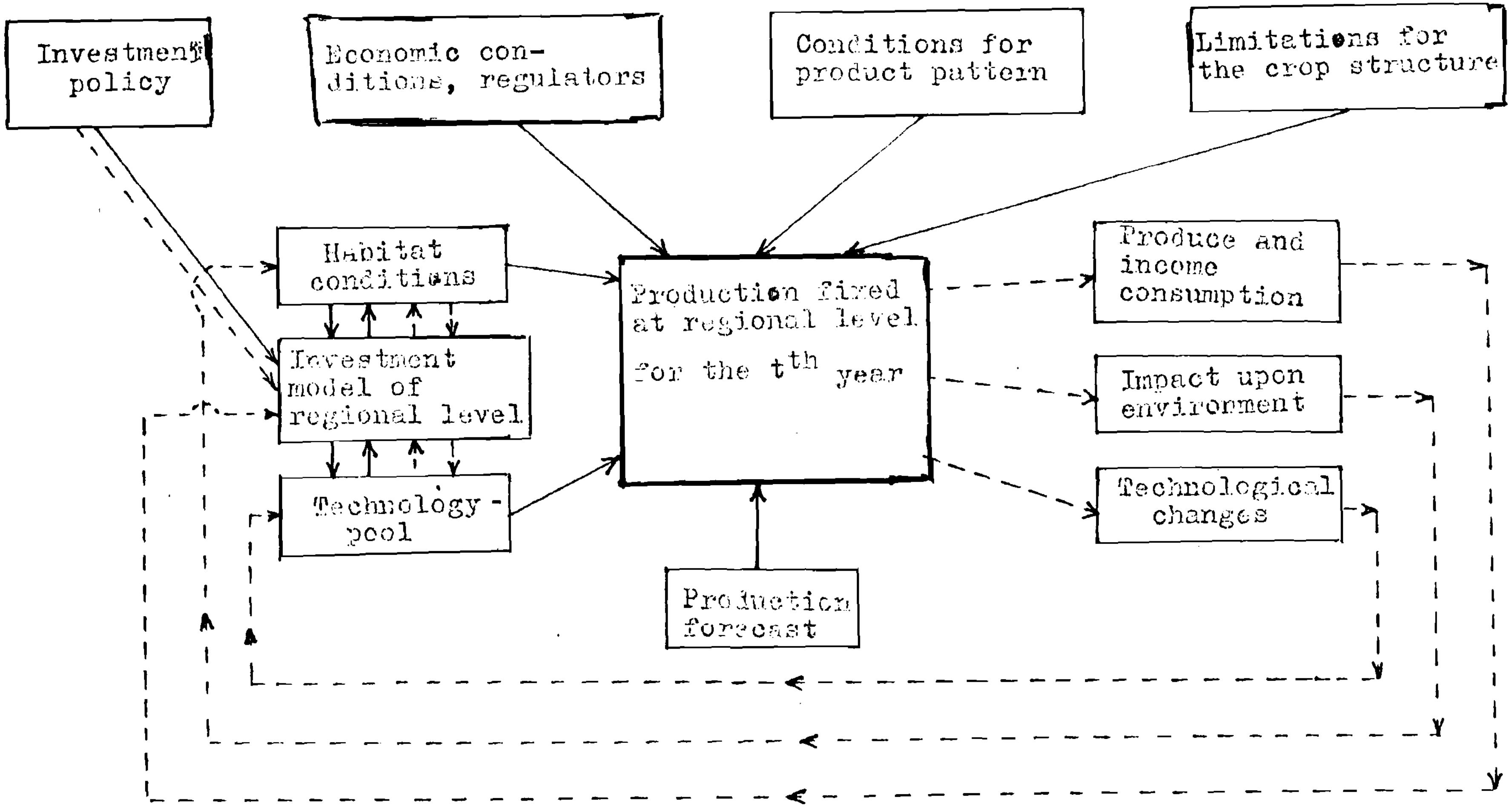
In the regional model the environment is represented by three characteristics:

a) the type of land
b) methods of cultivation
c) productivity level

5-7 land types are considered for each region. Land type here means a larger area with a homogeneous basic productivity level and geographic conditions. The basic productivity level can be increased by amelioration or irrigation, and modified by land use or technology.

Let $x_{sqr}(t)$ denote the area of land type q in the year t, with the s-th habitat type, and r-th productivity level. The actual values of these parameters are stored in the land-data bank $(s, q, r) \in I(t)$.

The area $x_{sqr}(t)$ can be used for crop production. Further let $z_{sqrhn}(t)$ denote the area used for the production of the n-th crop; here h refers to the technology applied including the amount of fertilizer used.



The continuous line represents the effects prevailing in the t^{th} year of production.

The interrupted lines represents the feedbacks.

Figure 5. Model at regional level

Obviously, the inequality

$$\sum_{h}\sum_{n} z_{sqrhn}(t) \leq x_{sqr}(t) \qquad (s,q,r) \in I(t), \quad t \in \{1,2,...T\}$$

holds.

Land Use Constraints

Area constraints developed according to land type ensure the fulfilment of the crop rotation requirements. These are of the following types:

- -- those representing the ratios between the area of certain crops or groups of crops
- -- those limiting the area of certain groups or groups of crops.

$$\beta^{1}_{sqn_1} \sum_{r}\sum_{h} z_{sqrhn_1}(t) \leq \sum_{r}\sum_{h} z_{sqrhn_2}(t) \leq \beta^{2}_{sqn_1} \sum_{r}\sum_{h} z_{sqrhn_1}(t)$$

with n_1, $n_2 \in \{1,2,...N\}$, $s,q,r \in I$

$$\sum \sum z_{sqrhn}(t) \leq \beta_{sqn} \sum_{r} x_{sqr}(t)$$

$t \in \{1,2,...T\}$

The latter means limitations on the frequency of land usage for individual crops. Table 8 shows the limitations due to constraints on crop rotation.

Production Constraints

Production constraints should be determined according to the behavior of the system. After the distribution of investment goods, the production of the major field crops in the regions is also determined. This should be done by setting lower bounds. At the beginning no limitations will be placed on the rest of the crops, and the volume and structure of production will be determined by income controls and the maximization of the netw income. If this method does not lead to a national production structure which meets the internal demand and corresponds to export requirements, then stricter limits will be set for the production structure in the regions, together with a modification of economic controls.

Let $y_{sqrhn}(t)$ denote the yield of the n-th crop in year t on the habitat characterized by the parameters s,q,r using

Table 8. Limits due to crop rotation constraints (in percentages of the total area)

Crop, group of crops	Crop rotation constraints	Non irrigated production Flat areas lower	 upper	 Hilly areas lower	 upper	Irrigated production lower	 upper
		bounds		bounds		bounds	
1. Wheat[x]	max. 2 years in monoculture	-	-	-	-	-	-
2. Rye	even in monoculture	-	-	-	-	-	-
3. Winter barley	max. 2 years in monoculture	-	-	-	-	-	-
4. Spring barley	50 % of red clovers as a min.	50 % red cl.	-	50 % red cl.	-	-	-
5. Rice	max. 2-3 years in monoculture	-	-	-	-	-	60 %
Winter grains /1+2+3/	min. 40 % in hilly areas	-	-	40 %	-	-	-
Grains /1+2+3+4/	max. 2 years after one the other	-	67 %	-	67 %	25 % alfalfa	-
6. Corn	even in monoculture	-	-	-	-	-	-
7. Potatoes	4 years to be left out	-	20 %	-	20 %	-	20 %
8. Sugarbeet	4 years to be left out	-	20 %	-	20 %	-	20 %
9. Sunflower	4 years to be left out	-	20 %	-	20 %	-	20 %
Root crops /6+7+8+9/	max. 30 % in hilly areas	-	-	-	30 %	-	-
10. Peas	4 years to be left out	-	20 %	-	20 %	-	20 %
11. Soybeans	4 years to be left out	-	20 %	-	20 %	-	20 %
One year papilionaceal /10+11/	-	-	-	-	-	-	-
12. Alfalfa[xx]	3 years to be left out	-	25 %	-	25 %	-	25 %
13. Red clovers	4 years to be left out	-	20 %	-	20 %	-	20 %
Pereuniat papilionaceal /12+13/	min. 20 % in hilly areas	-	-	20 %	-	15 %	-

Notes: x Only where rye can be cultivated and after amelioration
xx Only where red clovers can be cultivated and after amelioration

technology h. These yield values should be determined by a separate yield prognosis module.

The total production of the n-th crop in a region in year t is

$$Y_n(t) = \sum_s \sum_q \sum_r \sum_h y_{sqrhn}(t) \cdot z_{sqrhn}(t) \quad .$$

Limits can be put on production in the following form

$$y_n^{(o)}(t) = y_n(t) = y_n^{(1)}(t)$$

Technological Constraints

Constraints on technology in the regional production model are given for the vectors $\underline{G}_{sqhrn}$ representing the most important resource requirements of the technology during the peak periods of production.

The availability of machinery of sufficient quantity and quality is the basic precondition of production.

Individual groups of machinery can be used in a number of different operations, hence the same machine may be depicted in different elements of the vectors describing technologies for the production of different crops. This represents the use of a particular machine during different working periods.

The total machinery requirement in the t-th year is represented by the vector:

$$\sum_s \sum_q \sum_h \sum_r \sum_n z_{sqhrn}(t) \cdot \underline{G}_{sqhrn} = \underline{G}(t)$$

Let us suppose that there are L types of machinery in the description of capacities, i.e. in the vector $\underline{G}$. Let us now divide the indices of $\underline{G}$ into L groups, $I_1, I_2, \ldots I_L$, in such a way that indices in one group represent capacity requirements for the same type of machinery in the different working periods. Then the requirement for the i-th type of equipment is:

$$g_i = \max_{j \in L_i} \xi_j$$

where ξ_j is the j-th coordinate of $\underline{G}(t)$ and let

$$\underline{g} = \{ g_i \}_i \quad .$$

The capacity requirements ξ_j are given relative to the total capacity.

Let us now suppose that, at the beginning of the year, the region has $\underline{g}^o$ amount of machinery and $\underline{\hat{g}}$ amount of new machinery purchased in a given year. The coordinates of $\underline{\hat{g}}$, $i \in \{1,...,L\}$ are integer values. The conditions for the realization of the production program characterized by the z_{sqrhn} variables can be described as follows:

$$\underline{\hat{g}} + \underline{g}^o \geq \underline{g}$$

Obviously the vector $\underline{\hat{g}}$ is constrained by the actual financial conditions.

Economic Interrelationships and Objectives

This block of the model system will be elaborated together with the modeling of economic regulators at the planning level.

Characteristics of the Habitat

The data bank containing information about the natural conditions of the habitats is represented in each year by:

- the initial land type
- the possibility of amelioration
- the possibility of irrigation
- the yield level forecasted for the year 2000 according to the above three points, which gives the basic productivity of the habitat
- changes due to production or investment including the time required to complete amelioration or irrigation, and the type and extent of the eventual deterioration of the habitat (this information is needed to modify the basic productivity in order to know the actual productivity)

The consequences of the technology applied are determined by the environmental module.

Environmental Effects

The following are considered as negative effects of agricultural technologies on the soil and the environment:

a) Deterioration of the soil structure

The use of heavy machinery may lead to changes in the water management characteristics of the soil (e.g. porosity, field capacity, saturated conductivity). These effects are noticeable mainly when operations are carried out on irrigated soil. Using the available data, the extent of changes in soil parameters can be estimated.

b) Erosion

In order to determine the extent of erosion, we use the CREAMS model or the Universal Soil Loss Equation. In order to use the CREAMS model it must be calibrated according to Hungarian conditions.

c) Changes in pH

According to Hungarian and foreign literary sources, harmful changes in soil acidity occur only on some types of limeless soils. Changes in pH due to fertilizer application can be compensated for by adding lime to the fertilizer. The lime requirements and the sensitivity of the different crops are known.

The effects of all these factors on yields can be estimated using the data base.

d) Secondary salinization

According to a formula worked out by soil scientists, we can determine the critical ground water level in soils endangered by salinization. This value can afterwards be used to identify areas which should not be irrigated or where the amount of irrigation water applied should be limited.

The effects of agricultural technologies on the environment are analyzed by soil scientists who use existing models. Based on the methodology to be applied, the effects of the technologies used and of land use on the habitat will be studied and used to update the data bank for natural conditions.

Yield Prognosis

The methodology used for carrying out forecasts in the Survey of the Agroecological Potential has already been explained earlier (see heading "Genetic Development").

The forecasts available:

-- expected yields for the year 2000, for each habitat, climatic year type and crop, which we denoted as follows

$$y_{kszn} \ ,$$

Where the indices have the meaning:

k = the number of the region
s = the soil type
z = the climatic year type
n = the crop;

-- the expected value of the yield using the frequency of the z-th climatic year type p_z:

$$E_z(y_{kszn}) = \sum_z p_z \cdot y_{kszn} = y_{ksn}$$

-- a need for amelioration along with the expected yield rise. The yield to be expected after amelioration was also given, denoted by

$$y^m_{ksn} \ .$$

-- the expected national average yield for each crop under the present circumstances or after amelioration. Here the following formulae were used:

$$y_n = \frac{\sum_k \sum_s y_{ksn} \cdot \delta_{ksn}}{\sum_k \sum_s \delta_{ksn}}$$

$$y^m_n = \frac{\sum_k \sum_s y^m_{ksn} \cdot \delta^m_{ksn}}{\sum_k \sum_s \delta^m_{ksn}}$$

δ_{ksn} denotes the area of the s-th habitat type in the k-th region. If the n-th crop can not be cultivated in the region, δ_{ksn} is set at zero.

δ^m_{ksn} denotes the same on ameliorated areas.

Using the values y_n and y^m_n and the yield curves explained earlier on, we determined the expected yields due to genetic progress. Let $y_n(t)$ and $y^m_n(t)$ denote the expected national average yield of the n-th crop in the t-th year respectively. Then we generate expected basic yields for each region and soil type in the following way:

$$y_{ksn}(t) = \frac{y_{ksn}}{y_n} \; y_n(t)$$

$$y^m_{ksn}(t) = \frac{y^m_{ksn}}{y^m_n} \; y^m_n(t)$$

As a consequence, we have the equalities:

$$y_n(t) = \frac{\sum\limits_{k,s} y_{ksn}(t) \cdot \delta_{ksn}}{\sum\limits_{k,s} \delta_{ksn}}$$

$$y^m_n(t) = \frac{\sum\limits_{k,s} y^m_{ksn}(t) \cdot \delta_{ksn}}{\sum\limits_{k,s} \delta^m_{ksn}}$$

In addition to the yield prognosis, we have the fertilizer requirements corresponding to these yields from experts in agrochemistry. The possibility of either falling below or superceding the fertilizer level is taken into account. If the deviation is within a certain range, reliable estimates can be made on its modifying effect on the yield. This will be worked out by soil scientists.

A similar forecast was prepared on the possibilities and effects of irrigation. Knowledge is available on areas in which irrigation works can be constructed and the expected rise in yields due to irrigated cultivation. Let $y^{\ell}_{ksn}(t)$ denote this increased yield.

Knowledge of the values $y_{ksn}(t)$, $y^m_{ksn}(t)$, $y^{\ell}_{ksn}(t)$ allows us to determine the expected regional average yields and the fertilizer requirements needed for the projection of an investment policy.

According to our hypotheses, the yield of the n-th crop is determined by the parameters (s,q,r) with s standing for habitat type, q for its condition (i.e. present, ameliorated or irrigated) and r for the productivity level. Thus for every $x_{sqr}(t)$ we have one of the $y_{ksn}(t)$, $y^m_{ksn}(t)$, $y^{\ell}_{ksn}(t)$. This will be further denoted by $y_{sqrn}(t)$. The actual yield is modified by technology only by the amount of fertilizer applied. Yields which are dependent on technology will be denoted by $y_{sqrhn}(t)$. The fertilizer requirement denoted by α_{sqrhn} corresponds to this value.

Technological Data Bank

The current values of the parameters of available machinery are kept in the technological data bank. The data bank consists of two independent parts, one for the machinery directly needed in production (tractors, harvesters, etc.), and the other for equipment needed for carrying out ameliorative investments and the operation of irrigation systems.

A character study of the machinery contains information on:

- the type of operation a machine can be used for,
- the necessary additional machinery,
- its capacity, and
- machine age and depreciation rate.

When a machine reaches a depreciation rate of 100 percent, the machine is removed from the data bank. The purchase of new machinery takes place after the production structure has been determined, taking into consideration

- the existing stock of machinery and
- the financial means.

The new machinery is then introduced into the data bank.

Machinery required for amelioration is dealt with separately, because it is supposed that it is different in type. Amelioration is also financed from other sources and its cost is not included in the cost of production. This machinery is represented in a similar way to that required in production.

Technology Generation

The technologies to be used in production are chosen in a separate module independently from the regions. This means that the technologies available for different regions are the same for all of them. In order to match the requirements of the different regions, this central module generates all workable technologies. The actual selection of the technology is made according to

- the natural characteristics,
- the existing stock of machinery, and
- the available financial resources.

Individual technology systems are given by:

- land type, its condition and productivity level, (s,q,r)
- the crop, n
- the type of technology, h.

Given the crop and land type, the technology system is generated according to

- -- the field size,
- -- the fertilizer response level, and
- -- the machinery applied.

The last item needs special clarification. All the technologies generated include all the operations required for production. However, they differ according to their

- -- capacity requirements and
- -- environmental effects.

With regard to capacity requirements, one should establish at least two technology systems:

a) one using machinery according to the minimal requirements, giving high yields under favorable circumstances but sensitive to any influencing factors of production, such as, for example, bad weather which causes delays in the operations.

b) another reserving additional machinery capacities suitable for production in the case of bottlenecks, as in the above example.

From the point of view of environmental effects, technologies complying optimally with the environment or more economical ones with some adverse effects should also be generated. Different production technologies should be generated for different fields sizes; these should include at least two, one suitable for larger farms, another for small household plots.

The technology generator produces vectors of the form $\underline{G}_{sqrhn}$ used as inputs of the regional production module.

The coordinates of the vector $\underline{G}_{sqrhn}$ express the capacity requirements with respect to the machinery in the different peak working times during the year.

Regional Investments

It is in the regional investment module that decisions are made year by year on:

- -- the location and extent of ameliorative investments
- -- the construction of new irrigation works
- -- the purchase of new machinery.

Available resources are of two types:

1) government funded for the carrying out of amelioration, denoted by $u_{k2}(t)$

2) part of the net income of the region to be invested in production, denoted by $u_{ko}(t)$.

The data bank on natural characteristics of the region contains information on the type and location of necessary ameliorative interventions and possible irrigation sites. The latter is only considered where major irrigation works are already in existence.

Let us denote the area to be reclaimed on the habitat (s,q,r) in the t-th year by v_{sqr}. Then

$$0 \leq v_{sqr}(t) \leq x_{sqr}(t) \quad .$$

Similarly, let w_s^i denote the area which becomes irrigable after the construction of irrigation works on soil type s. The cost of amelioration on one hectare is f_{sqr}, and the construction cost of the irrigation works is f_s^i . If $f_h(t)$ denotes the amount of capital to be invested in new machinery, then financial constraints will have the following form:

$$u_{k2}(t) \leq \sum_s \sum_q \sum_r f_{sqr} \cdot v_{sqr}(t)$$

$$+ \sum_s \xi_s^i \cdot f_s^i + f_h(t) \leq u_{k2}(t) + u_k(t)$$

$$f_h(t) \leq u_k(t)$$

The value of $f_h(t)$ is determined on the basis of technology requirements in the production module of the region.

When allocating investments, the criterion of optimality is the yearly benefits minus yearly costs related to the investments.

The problem is to maximize the above function over the set of possible investments.

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