



# Limits and Possible Consequences of the Development of Agricultural Production: Modeling Agricultural Situations in the Stavropol Territory, USSR

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THE DEVELOPMENT OF AGRICULTURAL PRODUCTION:  
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## FOREWORD

The Food and Agriculture Program at IIASA focuses its research activities on understanding the nature and dimension of the world's food situation and problems, on exploring possible alternative policies which could improve the present situation in the short and long term, and on investigating the consequences of such policies at various levels -- global, national and regional -- and in various time horizons.

One part of the research activities focussed on investigations of alternative paths of technology transformation in agriculture with respect to resource limitations and environmental consequences in the long term. The general approach and methodology developed for this investigation is being applied in several case studies on the regional level. The reason for the studies is not only to validate the general methodology but also to develop an applicable tool for detailed investigations for a particular region which could then be applied on a number of similar regions.

Furthermore, some specific aspects are being addressed in all these case studies which has been initiated within the IIASA's Food and Agriculture Program. This will allow the behaviour of various systems to be compared, according to the selected aspects, and analyzed (in different social, economic and natural resource conditions) according to the selected aspects. One of these case studies is of Stavropol, USSR, and covers the whole of this region.

This paper describes the first phase of the study, the problems in this region, the aims for solving them, and the first draft of the methodology which is based on the general framework developed at IIASA.

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## LIST OF ILLUSTRATIONS

### LIST OF TABLES

Table 1	Yields of the principle agricultural crops cultivated in the Stavropol territory, metric centners per hectare (1m.c.=100kg)	2
Table 2	Agricultural zones of the Stavropol territory	5
Table 3	Characteristics of agricultural enterprises in the Stavropol territory, 1978 (average size)	6
Table 4	Machinery powered	22
Table 5	Machinery non-powered, buildings	22
Table 6	Operations	26
Table 7	Operation definition of output unit	27
Table 8	Production	28
Table 9	Coefficients of water and wind erosion harmful to the environment	29
Table 10	Commodities (crops)	34
Table 11	Commodities (livestock)	35
Table 12	Production (livestock)	37
Table 13	Stavropol data - variable inputs	39
Table 14	Fixed inputs	42

## LIST OF FIGURES

Figure 1	Agricultural zones of the Stavropol territory	4
Figure 2	The structure of the agricultural system	9
Figure 3	Factors forming agricultural systems	11
Figure 4	Crop farming and the soil treatment system	12
Figure 5	The plant growing system	13
Figure 6	The feedstuff production system	14
Figure 7	The livestock breeding system	15
Figure 8	The agricultural management system	17
Figure 9	General diagram of a system of agricultural management	18
Figure 10	Functional scheme of a recursive imitation model of the agricultural production of a region	20
Figure 11	The production process divided into individual elements (part of the diagram)	24
Figure 12	Structure of the matrix of the linear programming model	31

## CONTENTS

List of Illustrations	iii
Subject	1
1. Natural and Economic Conditions of the Stavropol Territory	2
1.1 Agricultural Characteristics in the Stavropol Territory	2
1.2 Agricultural Zones of the Stavropol Territory	3
2. Problems of Agrarian Policy in the Stavropol Territory	7
3. The Functional Scheme of a Recursive Imitation Model	19
3.1 Data Base	19
3.1.1 Reference Book on Agricultural Crops	19
3.1.2 File of Principle Crop Rotations	19
3.1.3 Agricultural Lands and Their Characteristics	21
3.1.4 Livestock Production Branches	21
3.1.5 Reference Book on Agricultural Machinery, Equipment, and Power Engineering	22
3.1.6 Reference Book on Technology	23
3.2 Generator of Technological and Organizational Decisions	25
3.3 Generator of Climatic Conditions	25
3.4 Generator of Technical and Economic Coefficients	27
3.5 The Setup Module	30
3.6 The Main Decision Box	30
- Coefficients	37
- Principle Variables	38
- Evaluation of Ecological Consequences	39
- Principle Equations and Limitations	40
3.7 Reverse Link Module	43
3.8 Interface Modules	43
3.9 Optimization of the Structure of Motor Vehicles and Tractors	43
4. Principle Operation Mode of the Model	44



**LIMITS AND POSSIBLE CONSEQUENCES  
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A.A. Nikonov, V.I. Nazarenko, V.N. Popov, and V.G. Chertov

**SUBJECT**

The solution to the main problems which agriculture in the Stavropol territory is now facing, will in the end depend on the rational use of the production resources available (both natural and economic), as well as the agricultural production technology being employed. This task is now becoming of extreme importance, since the intensification of agricultural production (high application rates of fertilizers and pesticides, the construction of big livestock breeding complexes, the high level of intensity of tractor operation activities) has a negative effect upon the environment.

Since the climatic conditions of the territory are extremely diverse, a zonal approach to the estimation of the interaction and interdependence between the resources used, production technology employed and the environmental conditions would be adequate. The above approach would provide comparable results, since the zones have similar geographical, soil, climatic, hydrological, and economic characteristics, as well as systems of land management.

In the Soviet Union 44 regions have been identified where the introduction of an individual management system is considered expedient. But long-term systems analysis of agricultural production has proven the above management system to be indispensable to every large administrative unit (a region, a territory, a republic); this would make it possible to take into account all the features of the unit in question.

## 1. Natural and Economic Conditions of the Stavropol Territory

### 1.1. Agricultural Characteristics in the Stavropol Territory

In general the Stavropol territory is located in an area of the North Caucasus which is favorable for the development of an intensive large-scale agricultural production. The natural conditions of the territory are rather diverse, contrasting and contradictory. The Stavropol territory is characterized by a clearly manifested horizontal and vertical zonality with limiting factors, such as irrigation water, as well as frequent droughts and hot dry winds which impede agricultural development.

The volume of agricultural production for the period 1976-80 amounted to about 30% of the total output for this period. The population of the territory is 2.5 million with 350,000 persons being employed in agriculture.

The Stavropol territory occupies 80.6 thousand sq.km and is located between 41-45 degrees of eastern longitude and 43-46 degrees of northern latitude. The importance of this work is increased by the fact that the results obtained are applicable to many other regions with similar climatic conditions in the Soviet Union and worldwide.

This territory makes up about 0.36% of the total area of the USSR and the population about 1% of the total population of the Soviet Union. Yet the Stavropol territory provides about 2% of the total grain crop output for the country, 4% of the sunflower output, 9% total wool, as well as a considerable amount of vegetables, wine and fruits. Winter wheat, corn, sunflowers, and perennial grasses used as fodder are principle agricultural crops cultivated in the Stavropol territory, although about 50 species of agricultural plants in all are grown there.

Table 1 provides the average yield data of the principle agricultural crops for the recent three five-year periods.

Table 1. Yields of the principle agricultural crops cultivated in the Stavropol territory, metric centners per hectare (1 m.c. = 100 kg).

Crops	Average data for five-year periods		
	1966-70	1971-75	1976-80
Grain crops, total	15.1	16.0	18.6
Winter wheat	15.9	17.1	19.8
Corn for grain	17.0	15.1	12.3
Sugar beet	183	163	223
Sunflowers	9.7	9.7	9.4
Corn for silage	73	111	129
Hay (grasses)	13.8	15.3	18.7

During the past 15 years principle crop yields increased, except yields for corn for grain and sunflowers.



The Stavropol territory is an important source of livestock breeding products. 1.5% of the total cattle and pig population, and 4.5% of the total sheep and goat population of the Soviet Union are concentrated in this region. The Stavropol territory is an important source of pedigree young animals (fine-fleeced sheep) for other republics and regions of the USSR. Besides this the Stavropol territory produces a considerable amount of eggs and poultry.

Unfavorable climatic conditions account for sharp fluctuations in gross yields of agricultural crops. Thus, in unfavorable years the winter wheat yield makes up only 30% of the level obtained in favorable years, and this in turn has a negative effect upon the development of livestock breeding, thus unbalancing agriculture.

## **1.2. Agricultural Zones of the Stavropol Territory**

The high diversity of natural and economic conditions in the Stavropol territory has conditioned the specialization of agricultural production by zones. There are five agricultural microzones in the Stavropol territory characterized not only by special conditions of climate, soil cover, relief, land management, but also by population density, the prevailing types of agricultural enterprises, the range of agricultural crops and enterprise groups. The agricultural zones of the Stavropol territory are given in Figure 1.

The first, sheep-breeding zone includes the five north-eastern regions in the territory. This is the zone with the most severe climatic conditions, relatively poor light-chestnut soils, with an average slope of 36 degrees, and a rather flat relief; large areas are under natural pasture, and the zone has a low population density. From 1971-75 the share of sheep-breeding products averaged 46.3%, that of grain, 12.5%, and that of cattle-breeding, 17.8% of total output as expressed in monetary value.

The second grain/sheep breeding zone borders the first one and is the biggest, occupying more than 33% of agricultural land in the territory. Severe as they are, the climatic conditions here are still more favorable than those described above. The economy is of the more intensive type, with sheep breeding averaging 27.8%, grain crops 14.2%, and cattle breeding 21.3% of the total volume of agricultural output.

The third grain/cattle breeding zone, a considerable part of which is occupied by the Stavropol upland, includes central regions of the Stavropol territory with fertile chernozem soils and a favorable water regime. Besides grain crops averaging 14% of the total volume of agricultural output, sunflowers and sugar beets are cultivated here (the share of both crops amounts to 9.4%). Some farms practice pig and poultry breeding. Sheep breeding averages 19.7%, and cattle breeding 24.8% of the total volume of the agricultural output.

The fourth zone includes four regions bordering the Caucasian Mineral Water health resorts. This is the zone with the highest population density and relatively favorable soil and climatic conditions. It is characterized by a better developed poultry breeding, vegetable growing, fruit growing, and dairy and beef cattle breeding industry than in the other zones. Grain crops average only 8.2%, sheep breeding, 6.2%, cattle breeding, 31.3%, poultry breeding, 15.4%, and pig breeding, 8.3% of the total agricultural output.

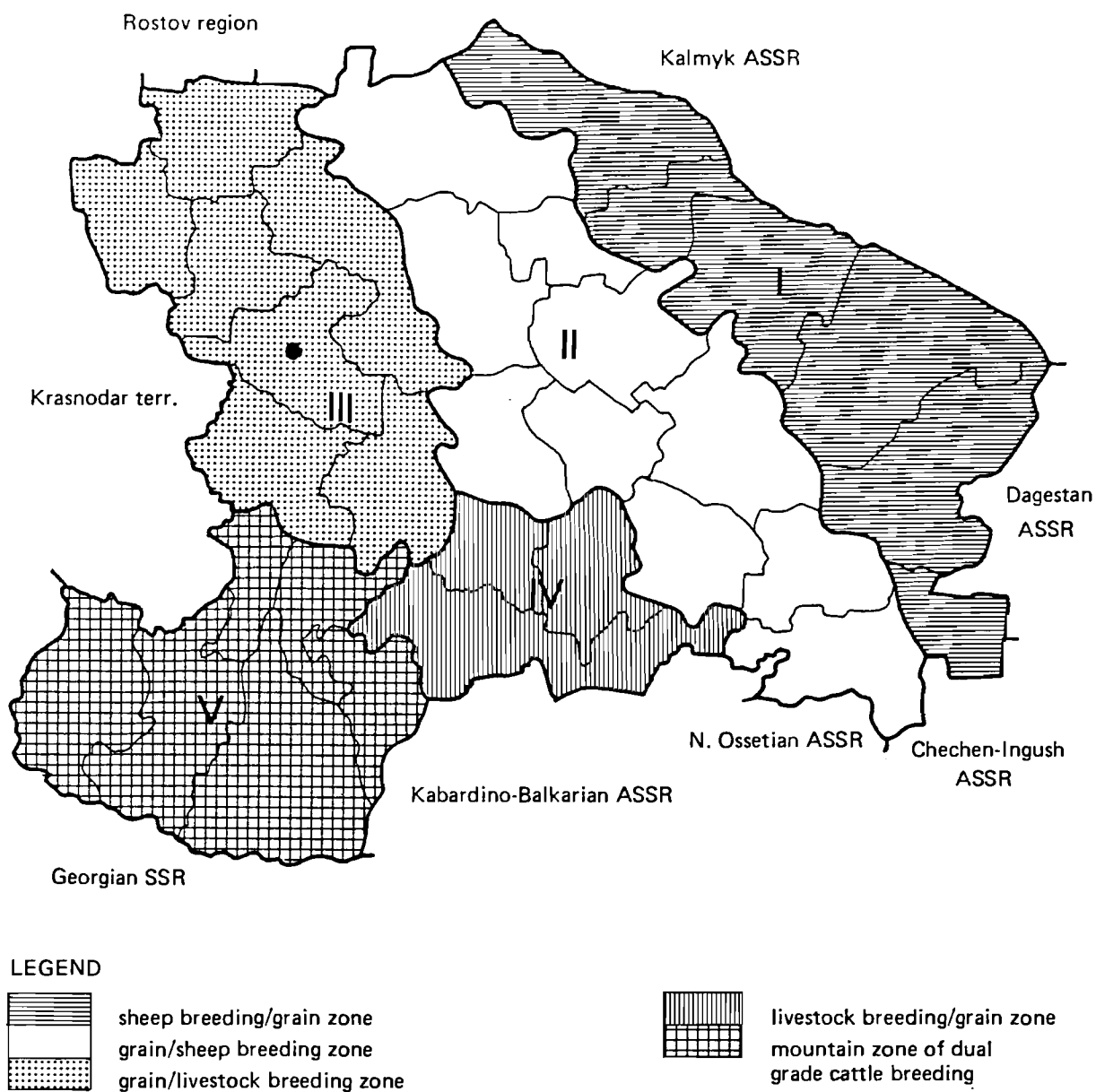


Figure 1. Agricultural zones of the Stavropol territory.

The fifth zone of mountain cattle breeding includes the state and collective farms of the Karachayevo-Cherkesskaya Autonomous region. These are farms with relatively low population density. The land is characterized by a highly intersected relief and large areas under subalpine pastures. Cattle breeding averages 37.6%, meat-and-wool sheep breeding, 26.8%, potato growing, 4.1% of the total agricultural output (see Table 2).

Table 2. Agricultural zones of the Stavropol territory.

Indices	ZONES				
	I	II	III	IV	V
Area, thous ha					
agricultural lands	1551.0	2174.1	1498.8	593.5	672.1
incl. arable lands	875.3	1653.6	1096.0	470.0	184.9
Soil types prevailing	light chestnut soils	chestnut soils, dark chestnut soils	chernozems	chernozems	mountain soils
Av. rating of arable lands, points	36	48	61	59	68
Av. annual precipitation rate, mm	260-396	370-450	450-530	480-600	400-1700
Hydrothermal coefficient	0.5	0.5-0.9	0.7-1.1	0.9-1.5	1.5
Height above sea level, m	0-80	80-100	200-800	200-900	500-3000
Density of rural population, people per sq. km	8.0	17.4	22.8	32.0	15.7
Types of collective and state farms prevailing	sheep breeding, grain/sheep breeding	grain/sheep breeding, grain/cattle breeding	grain/cattle breeding	fruit growing, grain/cattle breeding, vegetable growing	mountain cattle breeding
Av. gross agric. output for 1971-75 (comparable prices, 1973), mill. Rbls.	175.4	410.6	385.3	238.8	108.0
Av. % of total area:					
agricultural lands	24.0	33.6	23.0	9.2	10.2
wheat production	14.0	38.8	30.8	12.7	3.7
wool production	20.6	47.0	23.9	3.8	4.7

The general trend of agricultural development in the Stavropol territory is the specialization of agricultural production taking natural and economic conditions into consideration. The above trend resulted in the establishment of 11 types of agricultural enterprise in the Stavropol territory. The concept of production type farms implies a group of agricultural enterprises characterized by a similarity of: 1) their development conditions and the tasks being faced by them; 2) the structure of production branches and the final produce; 3) the

intensification levels; 4) the nature of the production processes (the structure of production means, types of raw materials, production technologies employed, the organization of labor, etc.).

The characteristics of collective and state farms according to their type of farming are given in Table 3.

Table 3. Characteristics of agricultural enterprises in the Stavropol territory, 1978 (average size).

Types of agricultural enterprises	Number of farms in one type	Characteristics of an average-size farm					total
		agricultural		machines and equipment,		supply,	
		land, thou ha	land thou ha	output, mill.Rbls	mill.Rbls	thou h.p.	
Grain/cattle breeding	126	13.6	10.9	4.4	1.1	22.0	70
Sheep breeding	72	27.5	16.0	3.8	1.3	19.3	69
Grain/sheep breeding	48	19.3	15.5	3.6	1.3	21.1	92
Fattening	29	9.5	6.0	2.4	0.6	12.3	47
Fruit growing	25	1.1	0.5	2.0	0.2	5.7	35
Grapevine growing	22	2.0	0.8	2.0	0.6	10.1	58
Mountain cattle breeding	20	19.0	3.0	3.0	0.7	18.5	72
Vegetable growing	19	4.4	3.0	2.3	0.8	14.4	66
Pig breeding	11	11.8	10.5	4.7	1.4	22.3	85
Poultry breeding	19	0.1	0.1	2.9	0.8	9.5	12
Apiculture	5	0.3	0.2	0.6	0.1	3.5	8

\* average data for 1976-78

It should be mentioned that the process of specialization, based on the concentration and inter-farm cooperation, resulted in the establishment of inter-farm enterprises dealing with the fattening of cattle, pigs, and sheep. There are 25 such enterprises in the Stavropol territory now. Historically, it turned out that collective and state farms of similar type, have a similar size as well; they differ in legal aspects (in the form of property, in the means of production, in the way the final produce is sold, etc.) rather than in the intensification level, organization and production technology.

Based on the above, all the state and collective farms can be grouped to form certain types.

The total gross output of the state and collective farms in the Stavropol territory as expressed in monetary value (comparable prices, 1973) amounted to:

	Annual average for 1971-75	Annual average for 1976-80*
Total gross output (mill. Rbls)	1733	1935
with the share of:		
plant growing,%	45.3	44.8
animal husbandry,%	54.7	55.2

\* 1980 - estimated data

## 2. Problems of Agrarian Policy in the Stavropol Territory

The most important agrarian problems of today in the Stavropol territory are: erosion control, soil conservation; ensuring a steady increase in agricultural production and seeking to eliminate negative effects such as droughts, hot dry winds, etc; optimization of the structure of agricultural production and resource use.

At present, of the 4.3 million hectares of arable land in the territory, 1.240 thousand hectares are subject to erosion. Erosion decreases soil fertility, even causing complete loss of productive farmland. Effective soil erosion measures have been developed. In this connection the effect of the soil conservation practices on agricultural production has yet to be estimated.

Real damage to agriculture in the Stavropol territory is caused by droughts and hot dry winds which results in considerable fluctuations in grain production in some years. Thus, in 1976 the grain crop output made up 2428 thousand tons; in 1977, 4,628 thousand tons; in 1978, 5,374 thousand tons; in 1979, the total output made up only 2,136 thousand tons.

The system of agriculture developed at the Stavropol Research Institute of Agriculture for dry climatic conditions has the following features:

1. The rational distribution and specialization of major agricultural production branches taking into account the drought factor.
2. Optimum structure of sowing areas with obligatory bare fallow rotations.
3. A soil treatment system aimed at maximum accumulation, conservation, and the rational use of soil moisture.
4. Soil conservation practices (wind and water erosion control, water run-off control).
5. The implementation of agricultural afforestation and agrotechnical measures for the collection and preservation of water run-off to be used for local irrigation purposes.
6. The development of irrigation activities with all the necessary precautions taken to prevent water loss, secondary salinization, etc.
7. The development and introduction of new drought resistant varieties of grain and feed crops.

8. A fertilization system providing for increases in crop yield and a still more productive use of soil moisture.
9. The chemical and agrobiological reclamation of alkali soils.
10. Pest and disease control.
11. New organizational forms of using machinery and equipment; optimization of the machinery and equipment system.
12. The development of an adequate social infrastructure in arid regions.

The principle task is to achieve the maximum possible stabilization of production processes by their rational distribution and specialization, the development of adequate feedstuff reserves, the optimization of sowing areas and the size of agricultural enterprises. More than 40% of arable lands are planted to feed crops, because green fodder production is low in efficiency.

The fact that the problem can be stated necessitates a systems analytical approach to its solution. An agricultural system hinges on scientifically grounded rational organizational, economic and technological principles, and the rational management of agricultural production processes. The development of such a system with high profitability is aimed at in order to be able to meet the requirements of society in agricultural produce.

The major features of the enterprise system are as follows:

- the specialization and branch structure of production processes;
- the intensification level;
- the technology used and management of production processes;
- the way in which the major production resources, i.e. land, manpower, capital, and funds, are used.

The structure of the agricultural system is given in Figure 2.

Under the influence of current social and economic processes, socialist agriculture is undergoing radical qualitative changes. This results in subsequent changes in the structure of agricultural enterprises which are transformed from being units with a diversified economy to specialized enterprises; their cooperation with other agricultural enterprises and branches of the national economy gives rise to the establishment of interfarm and agroindustrial associations; a steady increase in intensification and concentration of production processes can be observed; many branches of agriculture start to use industrial technologies; the material and technical resources of agriculture are improved; the professional skill of workers is improved, and new industrial professions created. Thus, all the principle components of the economic system, e.g. equipment, technology, organization and management, undergo changes. All this requires large investments.

Under such conditions we cannot confine ourselves to the study of only some aspects of this versatile problem. The problem must be considered as a whole, as a multiplicity of components and their correlation; development processes should be dynamically considered and at all levels. This is why the problem of improving management systems in agriculture has recently become so immediate.

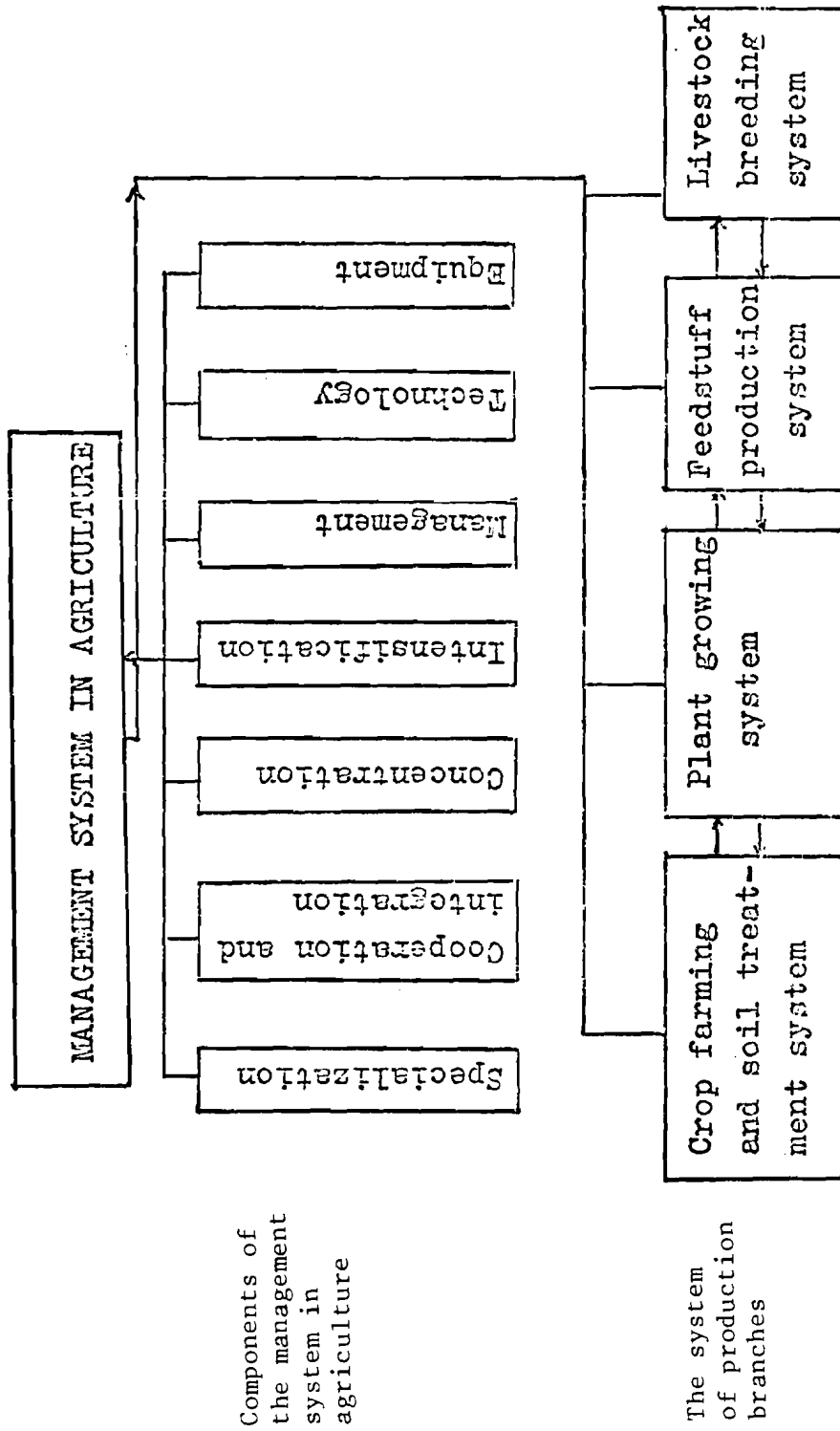


Figure 2. The structure of the agricultural system.

A system of management serves as a scientific and methodological basis for further development of the organization and management of individual enterprises, associations, and production branches. This is why this problem is of great scientific and practical interest.

The study of the management system in the country was started between 1956-60. By 1960 "Measures" had been developed for many regions to increase plant growth and livestock breeding output per 100 hectares of agricultural land. These "Measures" covered all branches of agriculture, but they included mainly agrotechnical and zootechnical recommendations, and economic problems were scarcely touched upon.

Between 1966-70 substantial work on the development of a rational system of agricultural management was carried out in 35 natural and economic zones throughout the country. The results obtained were summarized in monographs which proved very useful when scientific achievements were put into practice. But the problems of social and economic development and nature conservation were still not sufficiently outlined. In 1980, "A Management System Agriculture in the Stavropol Territory" was published. The "system" was considered to be the best in the Soviet Union. During the course of 17 years of research on management systems, comprehensive information has been collected at the Stavropol Research Institute of Agriculture. But present agricultural production requirements necessitate the development of new methodological approaches to the problem.

We are now facing the problem of developing a rational model of an agricultural system which would provide for a system layout of all the relevant interrelated factors (see Figure 3).

The substance of each production branch system shown in Figure 2 is given in more detail in Figures 4, 5, 6, and 7.

The concept "system of agriculture" implies a form of agriculture which is a complex of interrelated agrotechnical, reclamative, and organizational measures which are characterized by intensity of land use, as well as by methods of restoring and improving soil fertility.

A rational system of agriculture solves the following major problems:

- the productive use of all the land suitable for farming;
- the provision of a steady increase in soil fertility;
- the provision of optimum soil conditions (water, nutritive, air, thermal regimes, light regime, etc.), as well as soil conservation, and the preservation of nature.

In the Stavropol territory the following systems of agriculture are practiced:

- the fallow/ grain crop soil conservation system for eastern and north-eastern dry steppe regions;
- the grain/row crop soil conservation system for the central and foothill regions with and unstable soil moistening regime.

A plant growing system is predetermined by the whole system of management and depends on the system of agriculture; the major components of a plant growing system are the following: selection and breeding; seed production; the range of crops and varieties, regionalized for a particular area; the



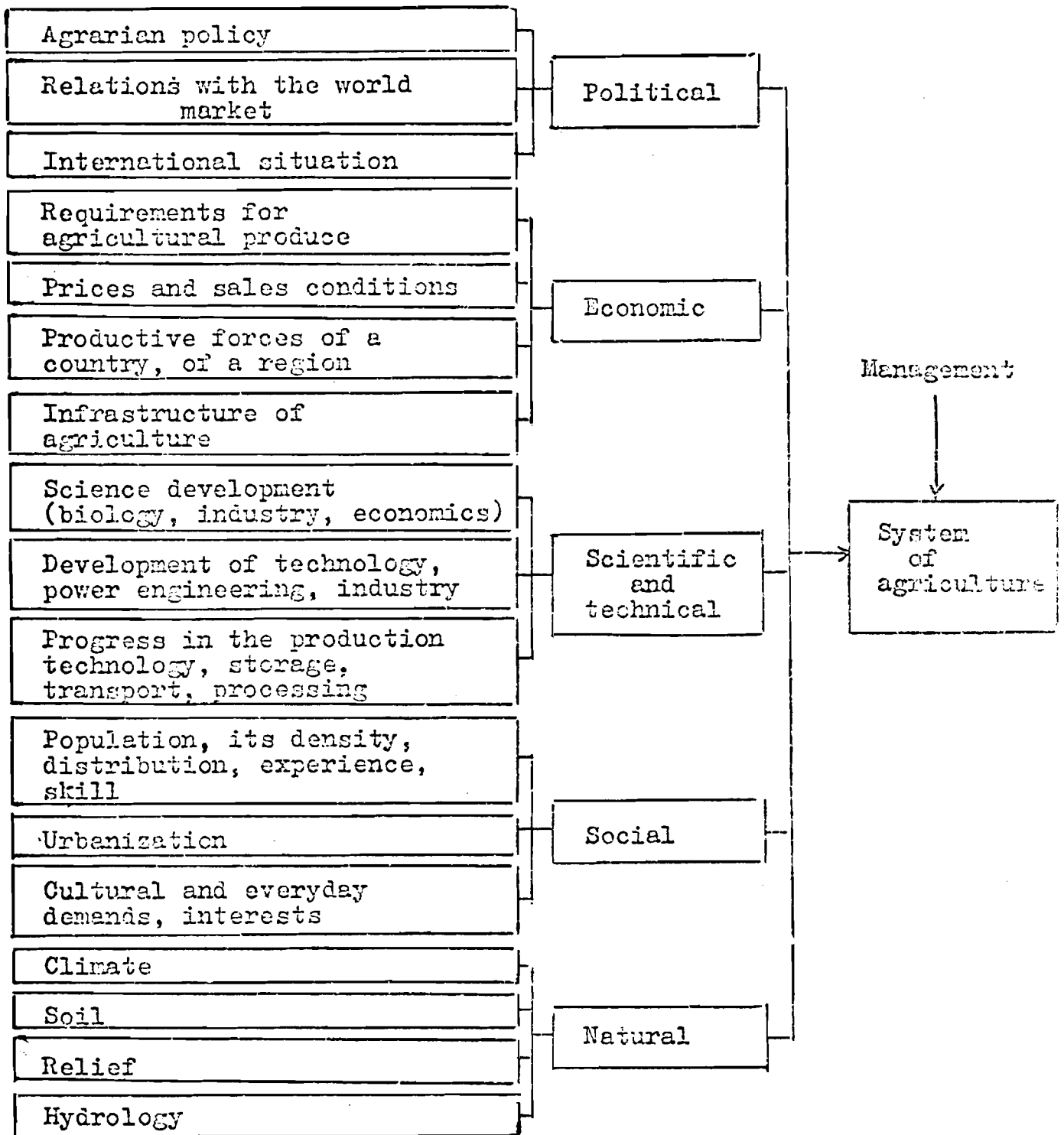


Figure 3. Factors forming systems of agriculture.

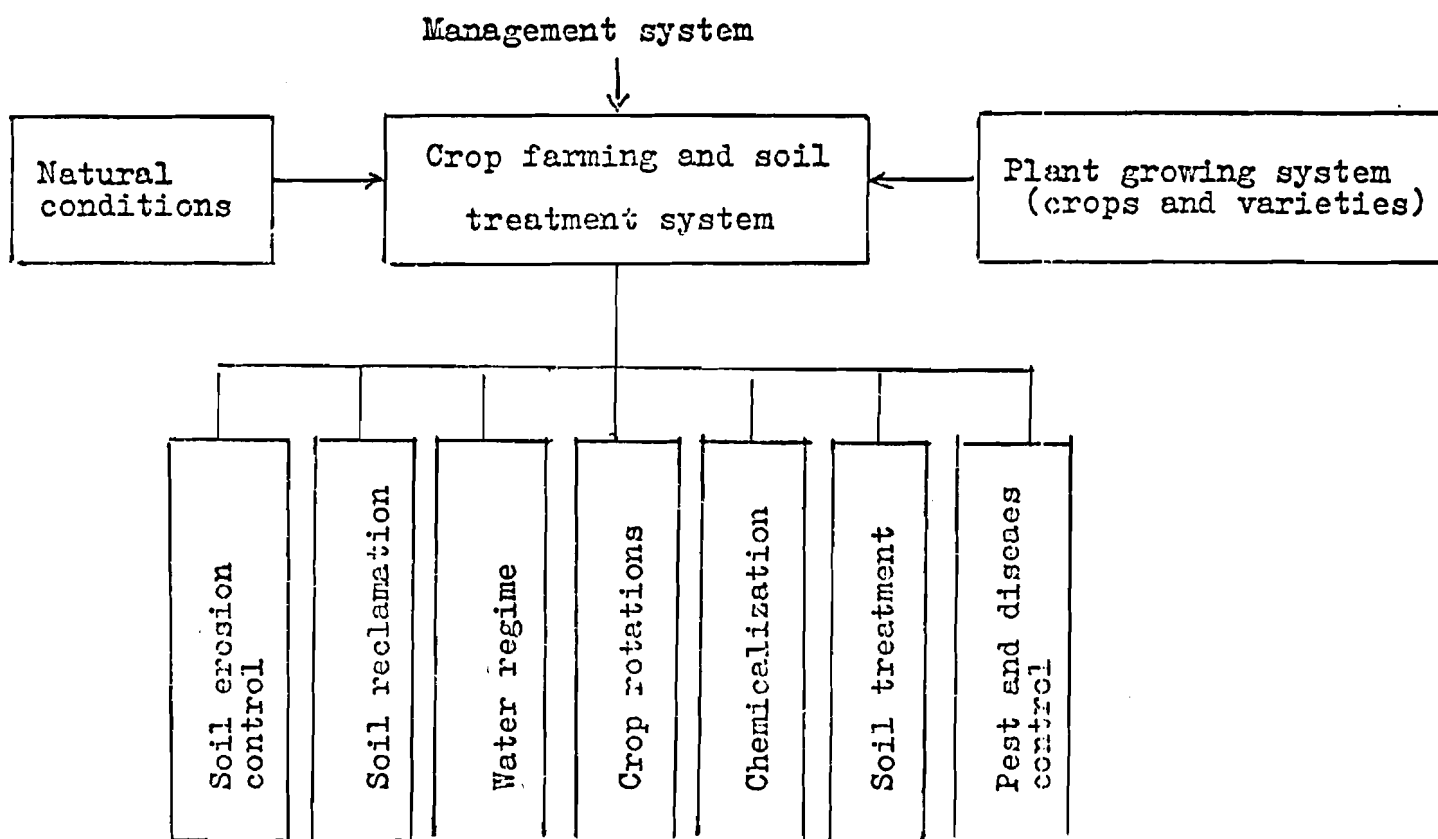
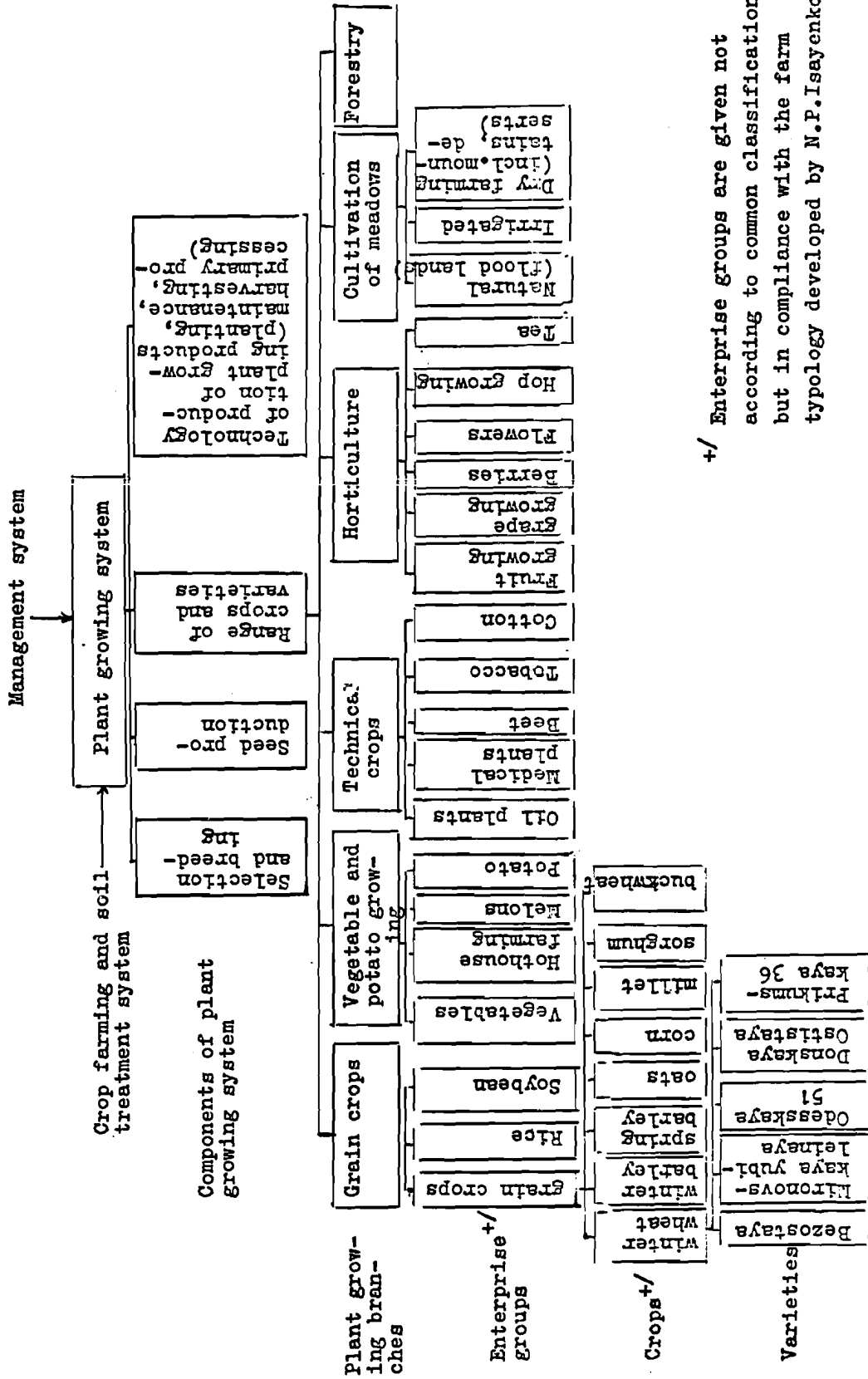


Figure 4. Crop farming and the soil treatment system.



+/ Enterprise groups are given not according to common classification, but in compliance with the farm typology developed by N.P. Isayenko.

Figure 5. The plant growing system.

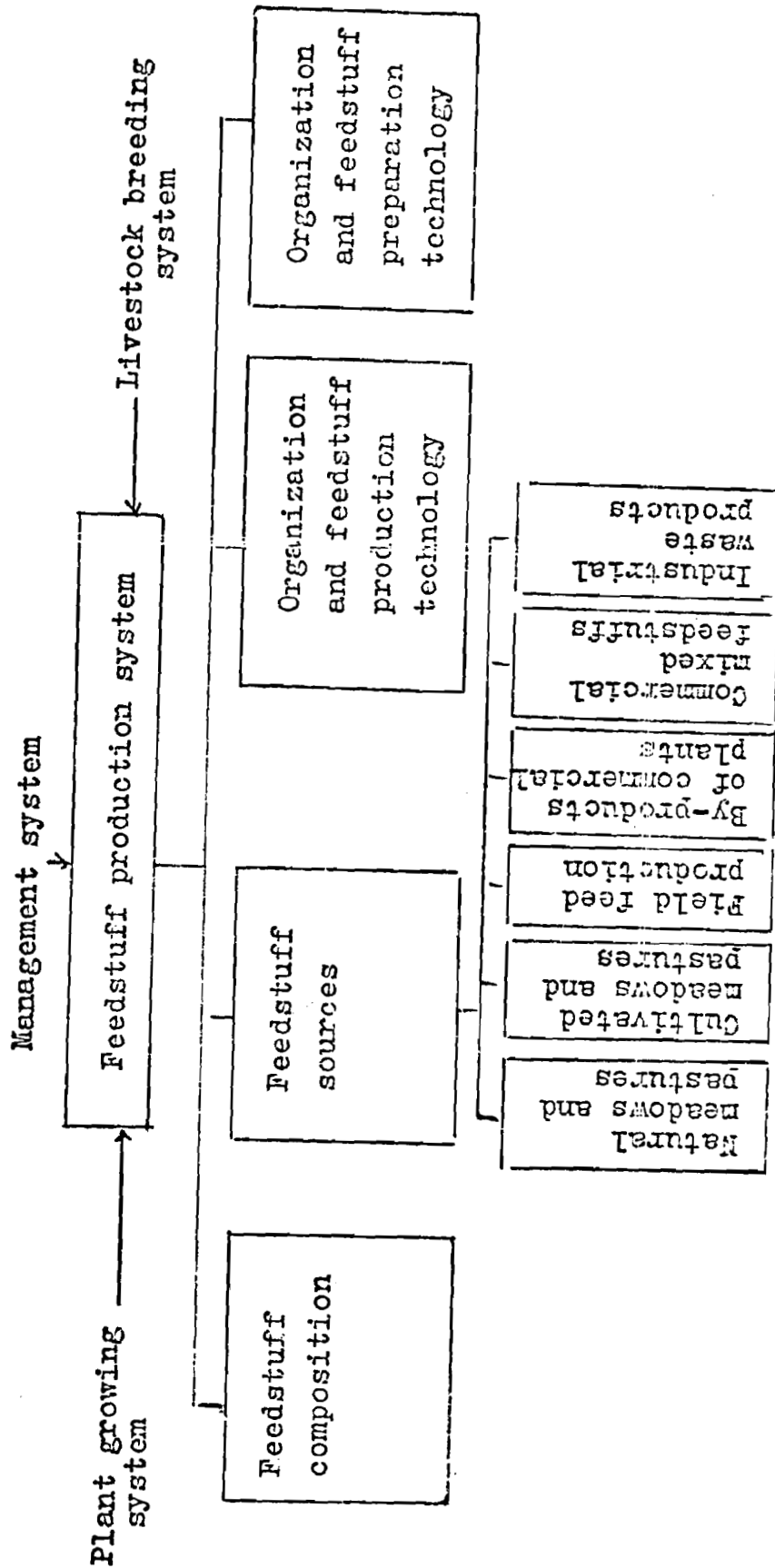


Figure 6. The feedstuff production system.

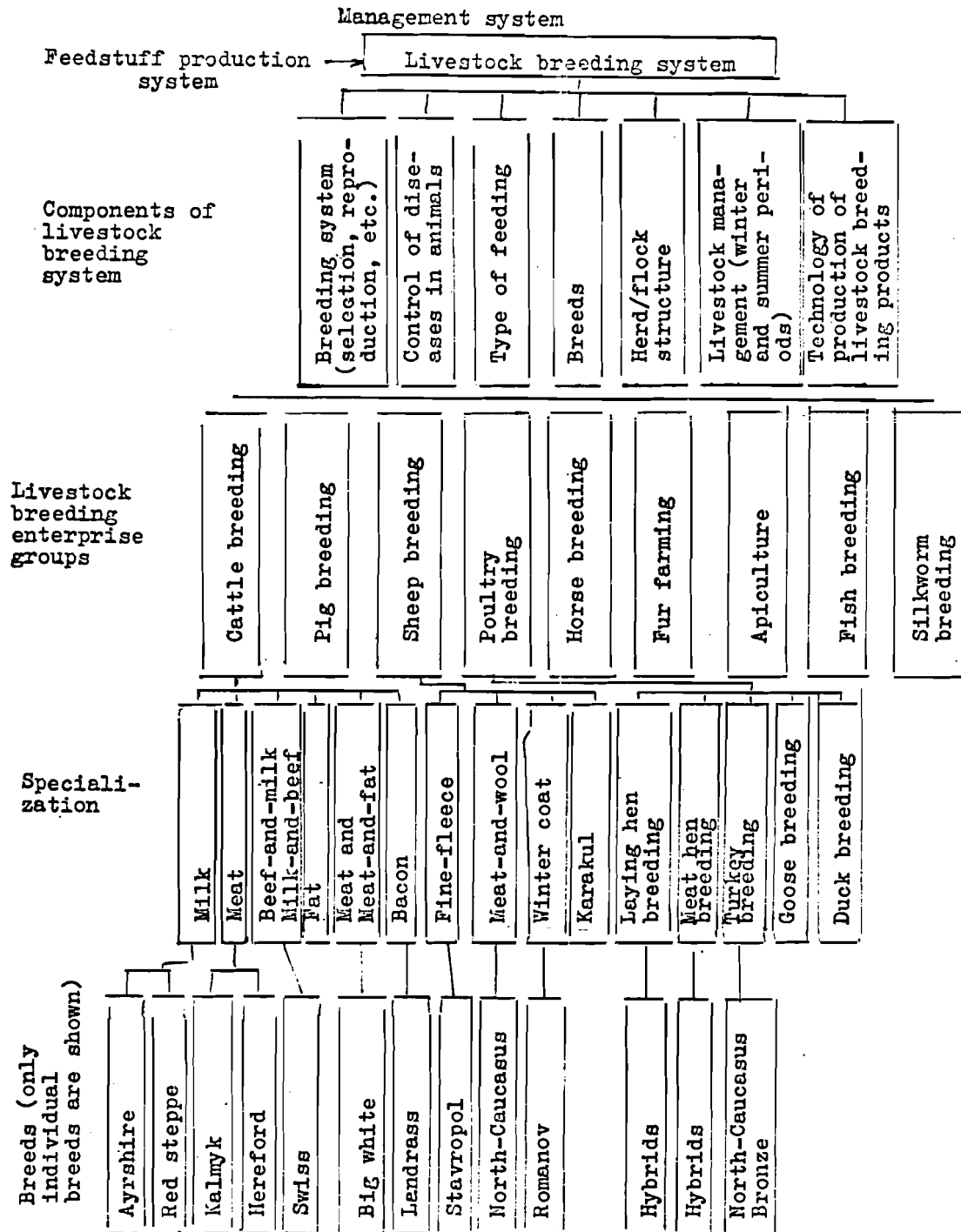


Figure 7. The livestock breeding system.

technology of production of plant growing products.

A steady intensification and specialization of production processes resulted in the formation of a feedstuff production system. This system is closely related to the plant growing and livestock breeding systems; it is characterized by principle components such as feedstuff structure/composition, feedstuff sources, and the organization of feedstuff production and the technology to be used.

The principle components of the livestock breeding system are the following: herd/flock structure; breeds; animal reproduction; livestock management during the different seasons (winter, summer); type of feeding; pest and disease control in animals; the production technology for livestock breeding products. All these components are characteristic of any livestock production branch. Naturally, they differ depending on the type of enterprise and the objective conditions of farm management. See Figure 8 for a summary of the above.

The stage reached in research on agricultural management systems is characterized by extensive use of system approaches, modeling in particular. Any model should include precise characteristics of production conditions. For Stavropol, such factors as droughts, dry winds and soil erosion should be taken into consideration, just as they should be for all other southern regions of the USSR.

Consequently, we are facing the problem of developing an economic and mathematic model of the agricultural management system in the Stavropol territory, taking into consideration the nature of the resource use and technologies employed.

The results of methodological work done by J. Hirs, D. Reneau, K. Frohberg, and other scientists at the International Institute for Applied Systems Analysis (IIASA) has proved to be the most applicable to our conditions.

In fact, the structure of a dynamic recursive model taking into consideration technologies and resources used as well as their effect upon the environment, can be represented in a general form consisting of four modules: the technological module; the module of the physical characteristics of agricultural plants and animals; the module of the effect of man's activity on the environment; and the decision module. Just informative interrelations between these modules would provide the logout of all possible technological characteristics, the characteristics of animals and plants, soil and climatic conditions, etc. Quite obviously the interaction between these modules results in the formation of a system of models shown in Figure 9.

There is no doubt that the logical adequacy of the above system provides for the close relation of the factors (technologies, environment, soil, plants, animals), with each factor having its own laws and correlations. The above laws and correlations existing in each group of factors should be used in specific models, with the final result which is obtained in the decision module accumulating all the possible alternatives. The model is designed to facilitate investigations into the possibilities of developing agricultural production for a long period to come (15 to 20 years) taking into consideration its effect upon the environment. Time increment is to be 1 year.

The principle object of the investigation is to find an optimum version of the structure of agricultural production with the maximum possible preservation of the ecological equilibrium and, at the same time, trying to eliminate (reducing to minimum) all the negative effects on the environment.

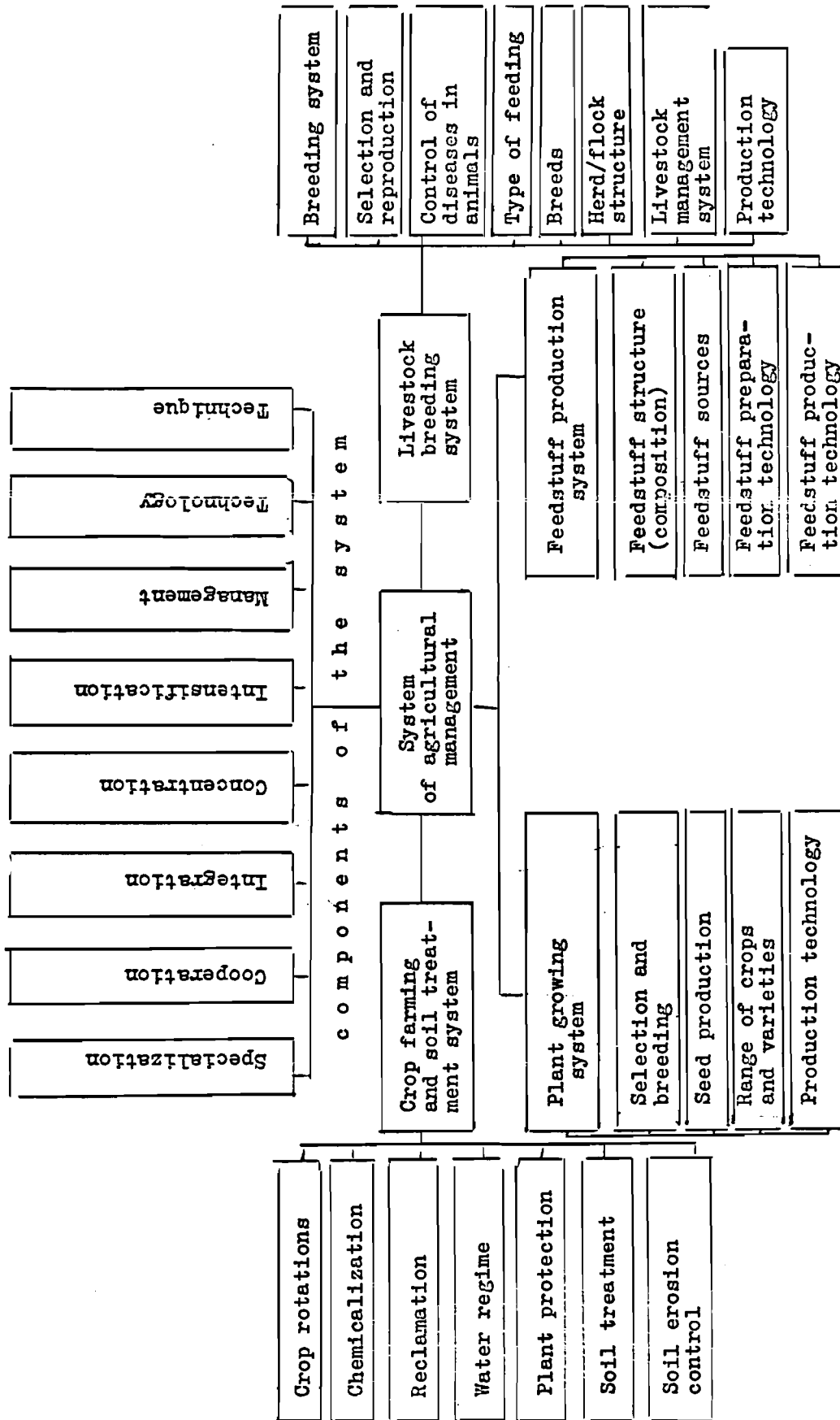


Figure 8. The agricultural management system.

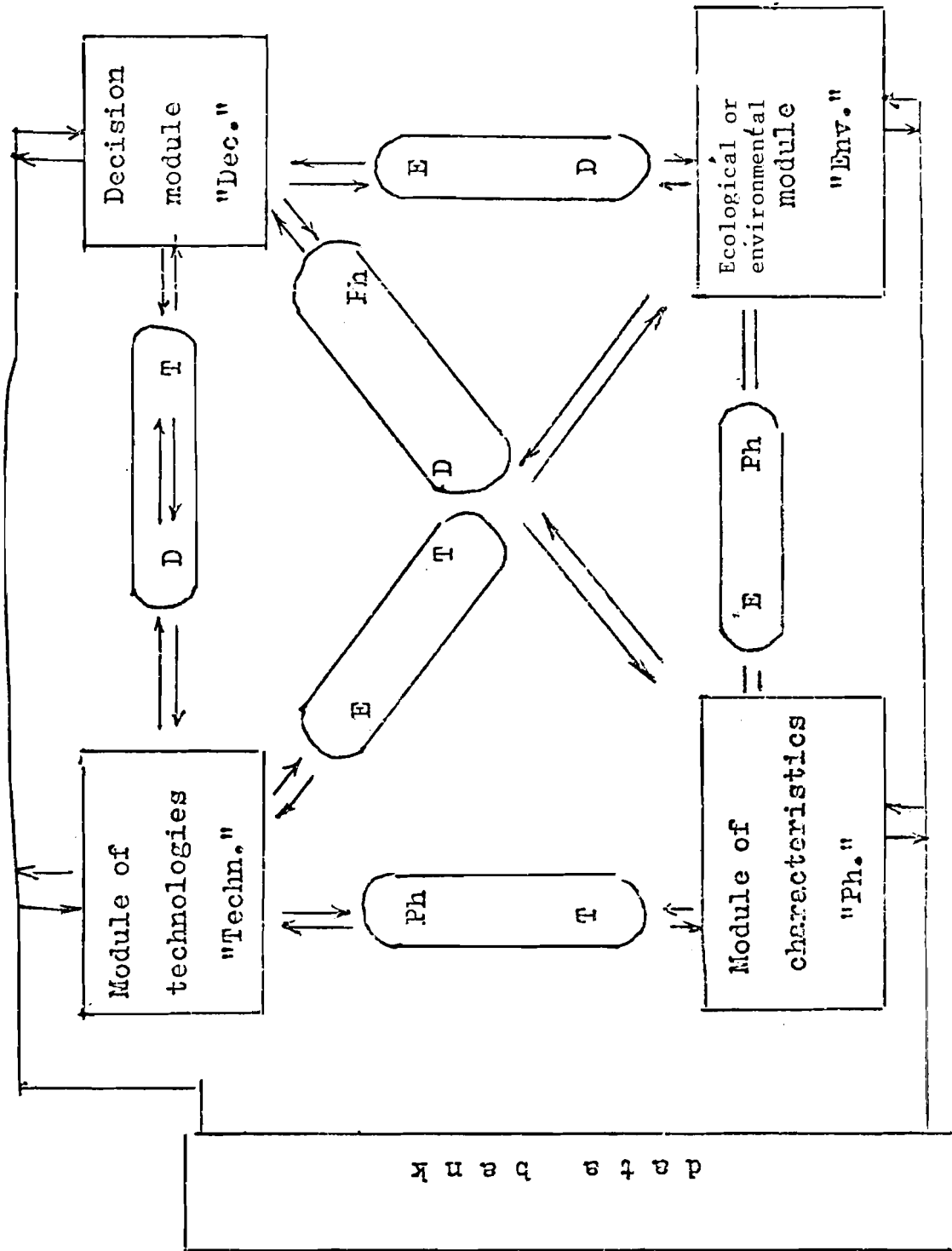


Figure 9. General diagram of a system of agricultural management.



Based on the above, we assume that a number of relevant questions will be answered. These are:

1. to determine the inner structure of the modules;
2. to determine a minimum volume of adequate information characterizing key positions and providing the characteristics of such factors as plants, animals, soils, and the damage caused to the environment;
3. interactions between modules;
4. how the recursivity requirement will be satisfied;
5. what does the concept "automation of the data bank replenishment process" imply?

### **3. The Functional Scheme of a Recursive Imitation Model**

The functional scheme of the model is given in Figure 10.

Given below are major functions of the modules and some alternative regimes of the model.

#### **3.1. Data Base**

The data base contains all the necessary information. It has the following divisions:

- a reference book on agricultural crops;
- a principle crop rotation file;
- a list of agricultural land in the region and its characteristics;
- the characteristics of livestock production branches with the structure of various feeding rations;
- a reference book on agricultural machinery and equipment and power engineering;
- a reference book on technology.

##### **3.1.1. Reference Book on Agricultural Crops**

This book contains the following information on every crop which can be cultivated in the region:

- the potential yielding capacity under the most favorable climatic conditions, and the best preceding crop on the most fertile soil;
- the economic characteristics regarding the inputs of materials, labor and energy with the use of a conventional (standard) technology excluding mineral fertilizers and other chemicals;
- coefficients for the conversion of the data on the primary and secondary produce to relative units.

##### **3.1.2. File of Principle Crop Rotations**

The file has a set of principle crop rotation schemes developed for every particular agroclimatic zone of the region.

Crop rotation schemes are classified by types, with the information available regarding the possibilities of the use of the schemes in any particular zone, land characteristics, as well as the possibilities of applying various technologies. Each crop is accompanied by the characteristics of the preceding crop (e.g.

Figure 10. The functional scheme of a recursive imitation model of agricultural production of a region.

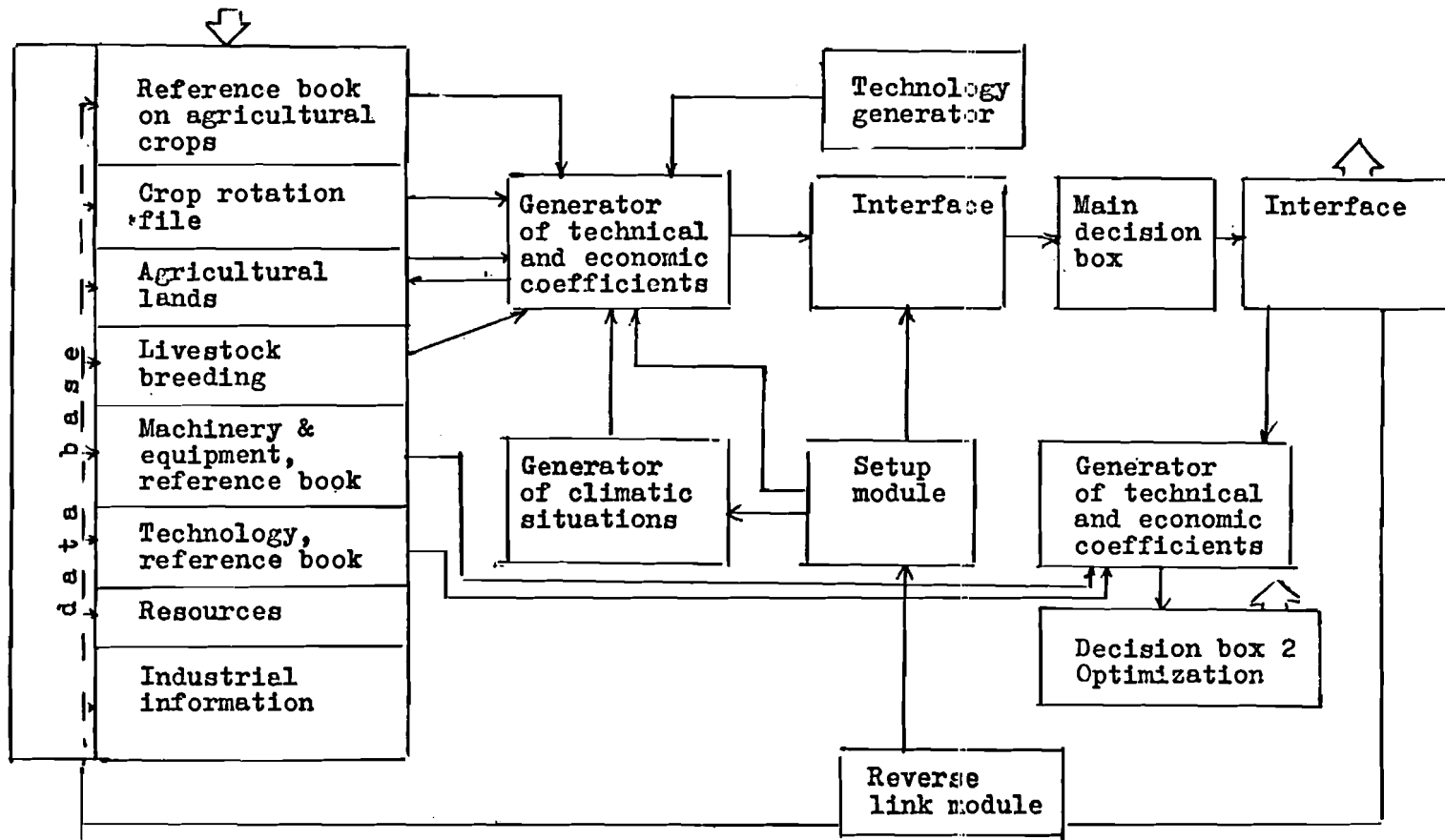


Fig. 10. Functional scheme of a recursive imitation model of agricultural production of a region

⇨ - information input/output

good, medium, bad). One and the same scheme can have several modifications. For instance, Sudan grass in one case can be used as greed fodder and hay, and, in the other, as greed fodder and silage.

### **3.1.3. Agricultural Lands and Their Characteristics**

A detailed soil regionalization is supposed to precede the decision to be made. The territory of the region to be modeled should be represented by a complex of homogeneous plots; each plot is characterized by a number of parameters, such as:

- acreage;
- type (virgin land, non-irrigated arable land, orchard, improved pasture, etc.);
- slope;
- natural fertility, points;
- content of primary plant nutrients: N, P, K;
- salinity;
- texture;
- terracing, contouring, soil slotting with vertical mulching, irrigation, drainage, etc.;
- planned or recommended soil treatment (terracing, contouring, slotting, irrigation, drainage, etc.);
- erosion hazard;
- wind direction.

In the formation of land classes, we form a set of the above mentioned characteristics that represent the land class for each of them (see paper by N. Konijn).

### **3.1.4. Livestock Production Branches**

In the data base this division is represented in the form of characteristics of herds/flocks of various structure, productivity levels, and fed on various rations. All characteristics are calculated per head (a cow, ewe, laying hen, sow). A herd/flock of one and the same structure can have different management parameters.

Herd/flock characteristics include the following indices (as calculated per head):

- yearly ration with the feed amount to be specified (green fodder, forage, hay, succulents, straw, etc.);
- output: milk, meat, wool, eggs, pedigree young animals;
- manure output;
- inputs (materials, money, labor, energy, capital investments).

**3.1.5. Reference Book on Agricultural Machinery and Equipment and Power Engineering**

The reference book contains information on the existing and promising types of machinery, equipment and power units: prices, performance, attendants, fuel or power consumption. The reference book provides possible alternative implements/tractor sets to be used for various soil treatments, crop cultivation and harvesting. The set of dates will be given according to Tables 4 and 5.

Table 4. Machinery powered.

	Unit	Tractors		Harvesters				Trucks	Other
		Small	Large	Grain	Corn	Sugar-beet	Feed		
		KN	KN	Kg/sec	Kg/sec	Ton/hour	Ton/hour		
1. inventory	Number								
2. average age	Years								
3. life expectancy	years								
4. working year	Hour								
5. season 1 availability	Hour/year								
6. season 2 availability	Hour/year								
7. average fuel usage	Kg/hour								
8. unit replacement cost	\$/unit								
9. cost change over t=1, t=20									

Table 5. Machinery nonpowered, buildings.

	Inventory	Depreciation rate % per yr.	Replacement		
			Purchase constraint (if any)	Cost	Change in cost or constraint for t=1, 20
Non-powered machinery					
Crop machinery	\$				
Livestock machinery	\$				
General	\$				
Buildings					
Dairy	m <sup>2</sup>				
Beef	m <sup>2</sup>				
Swine	m <sup>2</sup>				
Sheep	m <sup>2</sup>				
Grain storage	m <sup>3</sup>				
Hay storage	m <sup>3</sup>				
Silage storage	m <sup>3</sup>				

### 3.1.6. Reference Book on Technology

The reference book contains a comprehensive information on ways and means of putting production processes to practice, as well as on the processes proper causing qualitative changes of the object being processes; the choice of an adequate technology is closely related to physical, chemical, and physiological characteristics of the object. In agriculture such an object can be represented by soil, plants, or animals. In the course of a technological process an interaction between man and nature takes place resulting in both desirable and undesirable changes in the environment.

Agricultural production is known to consist of a number of individual processes with various production technologies, such as the production of grain, potato, sugar beet, milk, beef, pork, etc. The time required to complete the above processes consists of a working period when the production process is still under way with no labor consumed. During the final period physical, chemical, biological, and other processes take place.

The production process, in its turn, is subdivided into stages which are technologically completed parts of the whole production process. In plant growing, these are periods of sowing, crop care and harvesting. In dairy cattle breeding these stages are: management of the milking herd, raising of young animals according to development periods, and fattening; in pig breeding: keeping of sows for milking, barren and breeding, raising of youngsters by sex and age group, and fattening.

Working processes are integral parts of a production stage. "Working process" means cumulative efforts of one or several workers with the purpose of transformation of the objects of labor to another quality with the use of implements of production, thus getting the above objects ready for the completion of the production process, their further processing, putting them to other stages of production or exposing them to the influence of natural factors. Plowing, harrowing, cultivation, milking of cows, feeding of animals can serve as examples of the working processes.

It can be clearly seen that individual working processes are the very atoms forming the production stages and the production technology as a whole. Consequently, just the diversity of working processes predetermines the diversity of production technologies. The efficiency and adequacy of each working process will predetermine the efficiency and adequacy of the corresponding technology. A great diversity of working processes makes it possible to develop and estimate any agricultural production technology.

Every working process is to be characterized by the following parameters:

1. Set of machinery and equipment used.
2. Number of attendants.
3. Performance of the working assemblies, labor productivity.
4. Efficiency of the process.
  - 4.1 Labor consumption.
  - 4.2 Operation costs.
  - 4.3 Relative expenses.

Figure 11. Production process as divided into individual elements (part of the diagram).

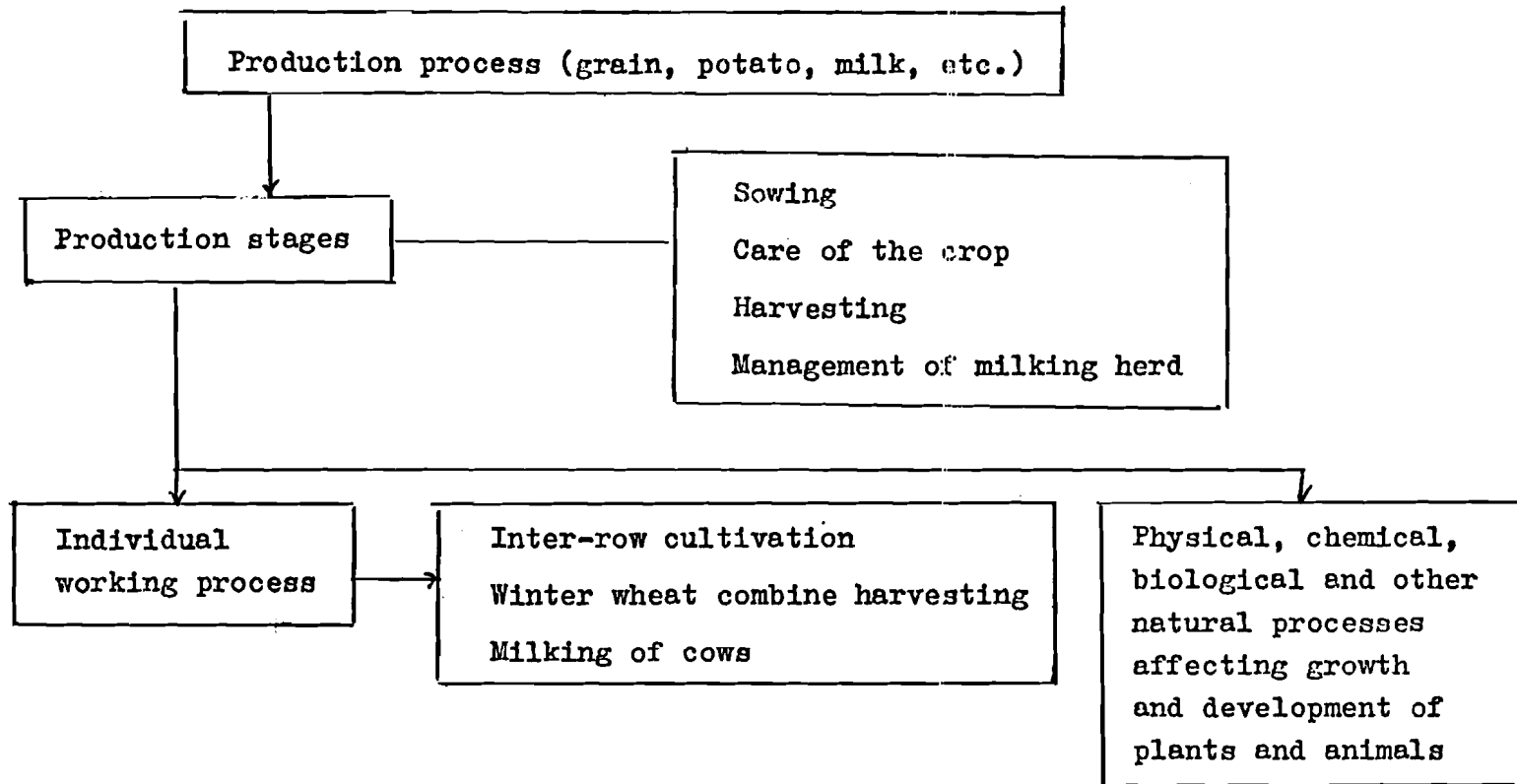


Fig. 11. Production process as divided into individual elements  
(part of the diagram)

- 4.4 Energy consumption (oil, gas, electricity, etc.).
5. Physical, chemical, biological, and other consequences of the working process.
  - 5.1 Nitrate accumulation, etc.
  - 5.2 Removal of N, P, with the crop yield.
6. Place and extent of most effective application of individual working processes with the following factors to be taken into consideration:
  - 6.1 Agricultural zone.
  - 6.2 Soil conditions.
  - 6.3 Range of crop varieties.
  - 6.4 Range of animal breeds.
  - 6.5 Climatic and other objective conditions of the production processes.
  - 6.6 Demography.
  - 6.7 Present state and future development of labor resources.
  - 6.8 Trends in scientific and technical progress.
  - 6.9 Volume and structure of capital investments.

All the necessary data for the description of technologies will be given in Tables 6 and 7.

### **3.2. Generator of Technological and Organizational Decisions**

This module will determine the possibility of applying alternative technologies and organizational decisions to a given plot with a concrete crop rotation system. The model can include several crop cultivation technologies suitable for the given crop rotation systems (see Table 8).

### **3.3. Generator of Climatic Conditions**

The imitative nature of the model is determined by the functions of this module to a considerable extent. Its mathematical "charge" can be both relatively simple and very complicated, and is almost sure to change in the process of the function of the model. The major requirement of the module is as follows: the module is to generate verisimilar climatic situations during a sufficiently long period of time, not only for the given years, but for the whole period as well.

The function mode of the generator is similar to that of the pseudo-random number generator which would make it possible to repeat the experiment after changing the source program but with a constant set of climatic situations.

Climatic situations generated for the whole zone are basic to the calculations of crop yielding capacity; the latter is then specified according to concrete conditions (local climatic factors, such as hail, heavy showers, frost, etc.). The following climatic factors are taken into consideration:

- precipitation rate by months and intensity;
- the number of days with atmospheric drought;
- average daily temperatures during the winter period,

Table 6. Operations.

Crop growing	
Divisions	Subdivisions
1. Soil preparation 2. Seeding 3. Plant treatment 4. Plant nutrition 5. Irrigation 6. Harvesting 7. Processing/storage	fall plant, spring grain plant, row plant, sugar beets close grown, row crops, sugar beets close grown, row crops, sugar beets close grown, row crops, sugar beets row crops, sugar beets, forage grain, forage, sugar beets grain, forage, sugar beets
Livestock Breeding	
1. Feed storage handling 2. Animal care 3. Manure handling	grain, hay, silage, monofeed dairy, beef, swine, sheep liquid, solid
Techniques for:	
Crop growing	Livestock breeding
1. Grain crops 2. Corn for grain 3. Sugar beets 4. Feed crops of hay, monofeed, silage 5. Corn for silage	1. Dairy cow 2. Dairy replacements 3. Beef cow 4. Swine 5. Sheep

- sum of active temperatures,
- velocity and direction of wind,
- solar radiation.

Additional factors:

- failure or damage to the crop resulting from an unfavorable combination of climatic factors during the winter/spring period;
- outburst of pest and disease epidemics causing a certain percentage of yield loss.

For the imitation and estimation of a climatic situation the following information on each factor is necessary:

- characteristics of the allocation of random variables,
- dispersion,



Table 7. Operation definition of output unit.

Operation \_\_\_\_\_ Code \_\_\_\_\_

Definition of Output Unit

Description of Alternatives	Units				
<b>Inputs</b>					
Labor					
Total crop	Hours				
Peak season 1	Hours				
Peak season 2	Hours				
<b>Machinery powered</b>					
Small tractor					
Peak season 1	Hours				
Peak season 2	Hours				
Large tractor					
Peak season 1	Hours				
Peak season 2	Hours				
<b>Machinery non-powered</b>					
	\$				
<b>Miscellaneous</b>					
	\$				

- range of variations (lower and upper limits),
- function of probability distribution, spectral characteristics.

The above characteristics are derived from retrospective analysis of actual data for the longest possible period, but not less than 30 years.

For these cases, all the characteristics of the crop module can be taken into account (see N. Konijn).

**3.4. Generator of Technical and Economic Coefficients**

The generator has a complex structure and derives coefficients for the matrix of the linear programming model. The module establishes close correlations between the data base, technology generatory and the generator of climatic situations. The module is based on the mathematical model of yield. The yield of any particular crop depends on many factors. It is impossible to list them and to take them all into consideration. But the principle chain can be represented as follows: "Soil and climatic situation-technology-organization-yield". Yield data are derived from functions reflecting correlations between biological and climatic factors with corrections being made for such indirect factors as results of selections and breeding work and improvement of the

Table 8. Production.

Production_____	Crop_____	Code_____	Standard land class			
Description of Alternative	Units					
Inputs						
Seed	\$					
Biocides	\$					
Soil preparation 1	Sp 1					
Soil preparation 2	Sp 2					
Seeding 1	Se 1					
Seeding 2	Se 2					
Plant treatment 1	PT 1					
Plant treatment 2	PT 2					
Plant nutrition 1	PN 1					
Plant nutrition 2	PN 2					
Irrigation 1	Ir 1					
Irrigation 2	Ir 2					
Harvesting 1	HV 1					
Harvesting 2	HV 2					
Processing/storage 1	PS 1					
Processing/storage 2	PS 2					
Output						
C <sub>1P</sub> Factors between 0-1						
Yield Adjust** between 0-1						

Notes:

- \* C<sub>1P</sub> Factors - effect this technique has on the amount of gross soil loss as measured by the universal soil loss 1  
C<sub>1P</sub> Factors
  - weed loss
  - insect loss
  - harvesting loss
- \*\* Yield Adjust - how much (if any) yield must be adjusted due to use of this technique

organization of production processes. The yield model also reflects correlations between some climatic factors and concrete technology and a crop rotation scheme. In a general form, the above function can be represented as the following:

$$U_{is} = U_{i \max} - \sum_{k=1}^k f(X_{ks}) + \Delta U_i$$

where:

- U<sub>is</sub> = the estimated yield of a crop when "s" technology is used;
- U<sub>i max</sub> = the maximum possible (potential) yield of the crop;

- $\sum f (X_{ks})$  = the sum of losses for all the K-factors;  
 $\Delta U_i$  = yield increment resulting from scientific and technical progress.  
           estimated yield of a crop with "s" technology used;  
           maximum possible (potential) yield of the crop;  
           the sum of losses for all the K-factors;  
           yield increment resulting from the scientific and technical progress.

The yielding capacity obtained is basic to the calculations of all the rest of the parameters of the model.

In the model in its first stage only water and wind erosion will be taken into account. For these purposes the coefficients of wind and water erosion danger will be used. Under traditional technology and according to land classes, such coefficients have the following meanings (see Table 9). With the help of these coefficients, each type of single crop or each type of crop rotation can be estimated. Moreover, some coefficients estimate new technological operations from the point of view of water and wind erosion. The yielding capacity obtained is basic to the calculations of all the rest of the parameters of the model.

Table 9. Coefficients of water and wind erosion harmful to the environment.

Crops or background	Coefficient of water erosion danger	Coefficient of wind erosion danger
Bare fallow	1.00	1.00
Sugar beet	0.90	0.95
Maize for grain	0.85	0.85
Sunflower	0.80	0.85
Potato	0.75	0.85
Spring cereals	0.60	0.75
Spring crops (mix)	0.50	0.75
Peas	0.35	0.75
Maize for silo	0.60	0.70
Row crops and perennial crop	0.50	0.70
Spring cereals and perennial crop	0.40	0.70
Winter cereals	0.30	0.30
Perennial grass (1st year)	0.08	0.08
Perennial grass (2nd year)	0.03	0.03
Perennial grass (3rd year)	0.01	0.01

Coefficients related to the livestock breeding output are obtained from the data base and are grouped in columns of the matrix of the linear programming model in the "ready made" form. Some corrections are related to the functions of temporary trends which reflect general trends of production branch development.

Calculations of the matrix coefficients is the main but not the only function of the module. The module has a reverse link with the data base; the reverse link is used in the correction of some characteristics of agricultural land depending on the climatic situation generated. For instance, heavy rains and dust storms can change the erosion hazard index of the area, as well as its suitability for certain types of crop rotation, provided no soil erosion control measures have been taken.

### **3.5. The Setup Module**

The setup module has the following functions:

- input and setup of the entry parameters of the model;
- input of limitations for resources and their increments;
- setup of a compute mode depending on the stage of the decision process.

### **3.6. The Main Decision Box**

In general the structure of the main decision box is given in Figure 12.

Such modeling principles were used to forecast agricultural development in the Stavropol territory until the year 2000 (A. Nikonov, V.G. Chertov, 1980) and proved their value.

The essence of what is proposed is as follows. For the sake of optimization, both individual crops (winter wheat, corn, beet, etc.) and crop rotation schemes. Crop rotation schemes will be preferred, being characterized by features which meet the requirements of the model: on the one hand (input information) - requirements for labor resources, machinery, fertilizers, pesticides, material and financial inputs, etc.; on the other (output information) - production of food and forage grain, feedstuffs in relative and absolute units, net profit, gross output, etc. (all the indices refer to one hectare of the crop rotation area).

It should be noted that one and the same rotation being regarded as a regular sequences of crops in time and space can have different values for similar characteristics depending on the soil, the production technology, fertilization and the plant protection program. in relative and absolute units, net profit, gross output, etc. (all the indices refer to one hectare of crop rotation area).

It should be taken into consideration that one and the same rotation being regarded as a regular sequence of crops in time and space can have different values of similar characteristics depending on soil, production technology, fertilization, and plant protection program. In other words, this approach covers the whole scope of problems related to the land use:

- crop rotation,
- soil cultivation practices,
- control of water and wind erosion,
- fertilizer application,
- plant protection.
- the crop yielding capacity depending on the preceding crop,



- agricultural machinery and equipment,
- the structure and rational technology of agricultural production.

Besides that, the above approach makes it possible to consider all the consequences related to the conservation of nature, as physical and chemical soil characteristics being important to our understanding of ecological phenomena, depend, to a considerable extent, on the preceding crop and a technology of agricultural production. It should be kept in mind that the crop rotation proposed reflect qualitative soil characteristics. The whole system of crop rotation has been taken into consideration, e.g.:

- dry farming field crop rotation;
- irrigation farming field crop rotation;
- dry farming feed crop rotation;
- irrigation farming feed crop rotation;
- crop rotation on saline soils;
- crop rotation on lands subject to wind and water erosion.

The following matrix will be used in this case:

Types of crop rotation	Land classes E					
	1	2	3		n-1	n
Dry farming field crop rotation	0	0	1		1	1
Irrigation farming field crop rotation	1	1	1		0	1
Dry farming feed crop rotation	0	0	1		1	1
Irrigation farming feed crop rotation	1	1	1		0	1
Crop rotation on saline soils	0	0	0		0	1
Crop rotation on lands subject to wind and water erosion	1	1	1		1	1

The problem thus having been settled, the following items will be defined:

- arable lands under various types of crop rotation/non-rotational crops;
- cattle and poultry production;
- output of plant and livestock breeding produce;
- sales volume of all kinds of agricultural produce beyond the limits of the territory;
- group of indices characterizing the economic consequences of man's activity (quantity and quality of resources, technologies being used, etc.). This group includes:
  - total soil losses;
  - water run-off values;

-- removal of pesticides with running water, etc.

In the model the following system of notations has been adopted:

$I = \{i\}$  - a spectrum of non-rotational crops, orchards, vineyards, crops in private plots, natural haylands and pastures; these crops (the volume of their production) will be estimated accordingly in Table 10.

"i" - denotes a crop:

- |                    |                                  |
|--------------------|----------------------------------|
| 1. - winter wheat  | 14. - maize                      |
| 2. - spring wheat  | 15. - vegetables                 |
| 3. - rye           | 16. - stock beet                 |
| 4. - winter barley | 17. - fruits                     |
| 5. - spring barley | 18. - peas                       |
| 6. - oat           | 19. - grapevine                  |
| 7. - millet        | 20. - alfalfa                    |
| 8. - buckwheat     | 21. - rape                       |
| 9. - sunflower     | 22. - sainfoin                   |
| 10. - sugar beet   | 23. - sudangrass                 |
| 11. - soy bean     | 24. - meadow and pasture grasses |
| 12. - potato       | 25. - melons                     |
| 13. - sorghum      |                                  |

$I^w$  - groups of plant growing produce

$W$  - index of crop groups

$I^1 = \{1,2,3,4,5,6,7,8\}$  - grain crops

$I^2 = \{9,10,21\}$  - technical crops

$I^3 = \{13,14\}$  - feed crops

$I^4 = \{16,25\}$  - feed root crops

$I^5 = \{11,18,20,22\}$  - green leguminous crops

$I^6 = \{24\}$  - meadow and pasture grasses

$I^7 = \{15\}$  - vegetables

$I^8 = \{17\}$  - fruits

$I^9 = \{19\}$  - grapevine

$J = \{j\}$  - livestock breeding production branches

1. - dairy cattle
2. - dual grade cattle
3. - beef cattle
4. - pork pigs
5. - bacon pigs
6. - fine-fleece sheep
7. - coarse hair sheep (mutton-wool sheep)
8. - hens (eggs)
9. - hens (poultry)

Table 10. Commodities (crops).

Variable	Unit	Initial Conditions		Base run changes t=1,20
		Relative Price (unit)	Constraint (if any)	
Winter wheat*				
Spring wheat				
Rye				
Winter barley*				
Spring barley				
Oat				
Millet				
Buckwheat				
Sunflower*				
Sugar beet*				
Soy bean				
Potato				
Sorghum				
Maize				
Vegetables*				
Stock beet				
Fruits*				
Peas*				
Grapevine				
Alfalfa				
Rape				
Sainfoin				
Sudan grass				
Meadow and pasture grasses				
Melons				

Notes:

- \* these variables will be taken into account first

m - kind of livestock breeding produce (see Table 11)

1. - meat
2. - hides
3. - milk
4. - eggs
5. - wool
6. - pedigree young animals

r - administrative or agricultural regions or zones,  
where r = 1,2,3, shown as "B", "W", "K" correspondingly.



Table 11. Commodities (livestock).

Variable	Unit	Initial conditions		Base run changes t=1,20
		Relative Price (unit)	Constraint	
Sheep meat	Ton*			
Swine meat	Ton*			
Bovine meat	Ton*			
Milk	Ton**			
Eggs	Mil.eggs			
Wool	Ton***			
Pedigree young animals	Thousand head			
Soil sediment				
Nitrates leached				

Notes:

- \* live weight
- \*\* basic condition
- \*\*\* washed wool

n - feedstuffs (components)

- 1 - feeding units
- 2 - protein
- 3 - dry mass
- 4 - green mass
- 5 - hay
- 6 - preserved feedstuffs (silage, haylage, silage made from one crop)
- 7 - grain wastes
- 8 - root crops
- 9 - potato
- 10 - other crops
- 11 - milk
- 12 - sugar/protein ratio
- 13 - protein/energy ratio

S - crop growing technology applied according to the adopted crop rotation schemes "K".

The model will include the most effective field and feed crop rotations being practiced in a given zone.

E = {e} - categories of non-irrigated arable land

e' - categories of irrigated arable land.

The identification of arable land categories is performed with the data on land resources rating being taken into consideration. Based on the above rating 6 arable land categories have been identified. These are as follows:

		Arable land thous. ha.
1	category - rates at more than 70 points;	294
2	category - 61-70 points;	382
3	category - 51-60 points;	1402
4	category - 41-50 points;	1491
5	category - 31-40 points;	499
6	category - less than 30 points.	217

For the estimation of an eroded, salinized, or irrigated arable land special coefficients have been introduced.

S' - livestock breeding technology; in the given model this index denotes heads of livestock population depending on the said technology (see Table 12).

h - kind of fertilizer:

1. - N
2. - P
3. - K
4. - Ca

Table 12. Production (livestock).

Livestock subdivision \_\_\_\_\_ Code \_\_\_\_\_

Description of alternative	Units				
<b>Inputs</b>					
Veterinary medicine, miscellaneous	\$				
Bedding	Ton				
Feed storage handling 1	Unit FSH				
Feed storage handling 2	Unit FSH				
Feed storage handling 3	Unit FSH				
Animal care 1	Unit AC				
Animal care 2	Unit AC				
Manure handling 1	Unit MH				
Manure handling 2	Unit MH				
Manure handling 3	Unit MH				
Product care 1	Unit PC				
Product care 2	Unit PC				
<b>Outputs</b>					
Yield adjustment*					
Principle (between 0.1)					
Manure (between 0.1)					
Animal waste (between 0.1)					

**Notes:**

- Yield adjustment principle - how much (if any) the principle output must be adjusted due to the use of this technique
- Yield adjustment manure - amount of manure provided that can be recovered for application
- Yield adjustment animal waste - amount of manure produced that will enter surface runoff water

**Coefficients**

- $\alpha_{eksr}$  ( $\alpha_{jeksr}$ ) - plant growing produce output per 1 hectare of the rotational area, "k"-crop rotation system ("i"-crop) with "s"-technology applied in "r"-region on the land of "e"-category;
- $\alpha_n$  - same for livestock feeding as calculated for the "n"-feedstuff component;
- $\beta_{mjs'r}$  - output of "m"-livestock breeding produce per one head of "j"-kind of livestock (poultry) with "s"-technology applied in "r" region;
- $\beta'$  - same for livestock feeding;
- $\gamma_{eksr}$  - labor input per unit area of crop rotation (or a single crop area);
- $\gamma'_{js'r}$  labor inputs per one head of livestock;

$f_{ke's}$	water requirements per one unit area of irrigated (e prime) arable land;
$f'$	- same, but in the peak period;
$Q_{kes'r}$	- requirements for the means of mechanization per unit area;
$q'_{j'sr}$	- same, but per one head of livestock;
$Q_{hkesr}$	- requirements for "h"-kind of a fertilizer;
$C_{kesr}$	- capital investment requirements per unit area;
$C'_{j'sr}$	- same, but per one head of livestock;
$\delta^d$	- coefficients characterizing pollution and soil losses by the "d" source;
$P_{sekr}$	- economic coefficients characterizing the produce output as expressed in monetary value (S=1), profit
$(P_{j'sr})$	(S=2), etc., per unit area (or per head of livestock);
$\bar{P}$	- cost of a unit of a purchased product.

**Principle Variables (see Table 13)**

$X_{kesr}$	- arable lands occupied by crop rotation fields;
$Y_{iesr}$	- arable land planted to "i"-non-rotational crops;
$X_{j's'r}$	- population of "j"-kind of livestock on state farms;
$Y_{j's'r}$	- same in private plots and households;
$U_{ir}$	- food product output in plant growing;
$U_{mr}$	- same in livestock breeding;
$Q_{ir}$	- feedstuff output in plant growing;
$Q_{mr}$	- livestock breeding produce output used for livestock feeding;
$Q_{jr}$	- number of pedigree young animals to be sold;
$W_{ir}$	- direct consumption of plant growing produce (food products);
$W_{mr}$	- direct consumption of livestock breeding produce (as food products);
$Z_{ir}$	- consumption of plant growing produce for livestock feeding;
$Z_{mr}$	- consumption of livestock breeding produce for livestock feeding;
$V_{ir}, V_{mr}$	- food and feedstuff purchase volume (plant growing and livestock breeding);
$P_{ir}, P_{mr}$	- sales volume of plant growing and livestock breeding produce beyond the limits of the region;
$P_{jr}$	- sales of pedigree young animals.

Table 13. Stavropol data - variable inputs.

1. Variable Inputs

Variable	Unit	Initial Condition t=0		Constraint (if any)
		Relative Price (unit)		
Energy - fuel	Ton*			
Energy - electricity	KWH			
Energy - heat	Kcal			
Fertilizer - N	Ton**			
Fertilizer - P	Ton**			
Fertilizer - K	Ton**			
Fertilizer - Ca	Ton**			
Biocides	\$			
Capital	\$/ \$			
ERD***	\$			
Purchased feed****	Ton			
Purchased feeder calf*****				

Notes:

- \* Ton of complex fuel
- \*\* active ingredient
- \*\*\* expenses research and development
- \*\*\*\* each must be defined by energy, protein and DM values of ingredient for each type of animal
- \*\*\*\*\* defined by weight, quality relative to present average quality in region

**Evaluation of Ecological Consequences**

$D_{eksr}^d$  - sum of losses/accumulations of detrimental substances in plant growing;

$D_{jst}^d$  - same in livestock breeding;

for

d=1 - total soil losses;

d=2 - water run-off;

d=3 - accumulation/leaching of nitrates;

d=4 - removal of pesticides with run-off water;

d=5 - ...

### Principle Equations and Limitations

All the variables of the model are assumed to have bilateral limitations.

In the structure of the model the possibility of limitations (maximum and minimum levels) is designated with the index "+"; for the resources the upper and the lower limits are designated with the indices "U" and "L" correspondingly.

The use of agricultural lands:

$$\sum X_{kesr} + \sum Y_{iesr} \leq S_r \quad (1)$$

The use of an arable land of a given category:

$$\sum_{e=1}^E X_{kesr} + \sum_{e=1}^E Y_{iesr} \leq L_{er} \quad (2)$$

The production of food products in plant growing:

$$U_{ir} = \sum_{k=1}^K \alpha_{eksr} \cdot X_{eksr} + \sum_{i=1}^I \alpha_{iesr} \cdot Y_{iesr} \quad (3)$$

the same in livestock breeding:

$$U_{mr} = \sum_{j=1}^N \beta_{mjs'r} \cdot X_{js'r} + \sum_{j=1}^N \beta_{mjs'r} \cdot X_{js'r} \quad (4)$$

Feedstuff production in plant growth:

$$Q_{irn} = \sum_{k=1}^K \alpha'_{n eksr} \cdot X_{eksr} + \sum_{k=1}^K \alpha'_{n iesr} \cdot Y_{iesr} \quad (5)$$

and the same in livestock breeding:

$$Q_{mr} = \sum_{j=1}^N \beta'_{m js'r} \cdot X_{js'r} + \sum_{j=1}^N \beta'_{m js'r} \cdot Y_{js'r} \quad (6)$$

### Balance Equations:

#### Food balance

a) plant growing:

$$U_{ir} - W_{ir} + V_{ir} - P_{ir} = 0 \quad (7)$$

b) livestock breeding:

$$U_{mr} - W_{mr} + V_{mr} - P_{mr} = 0 \quad (8)$$

**Forage balance**

a) plant growing:

$$Q_{ir} - Z_{ir} + V_{ir} - P_{ir} = 0 \quad (9)$$

b) livestock breeding:

$$Q_{mr} - Z_{mr} + V_{mr} - P_{mr} = 0 \quad (10)$$

**Limitations of principle resources**

a) labor (see Table 14):

in plant growing:

$$T \geq \sum_{k=1}^K \gamma_{eksr} \cdot X_{eksr} + \sum_{i=1}^I \gamma_{iesr} \cdot Y_{iesr} \quad (11)$$

in livestock breeding:

$$T' \geq \sum_{j=1}^N \gamma'_{js'r} \cdot X_{js'r} + \sum_{j=1}^N \gamma'_{js'r} \cdot Y_{js'r} \quad (12)$$

b) irrigation water (annual consumption):

$$P \geq \sum_{k=1}^K f_{ke'sr} \cdot X_{ke'sr} + \sum_{i=1}^I f_{ie'sr} \cdot Y_{ie'sr} \quad (13)$$

c) irrigation water (peak period):

$$\hat{P} \geq \sum_{k=1}^K f'_{ke'sr} \cdot X_{ke'sr} + \sum_{i=1}^I f'_{ie'sr} \cdot Y_{ie'sr} \quad (14)$$

d) means of mechanization:

in plant growing:

$$G \geq \sum_{k=1}^K q_{kesr} \cdot X_{kesr} + \sum_{i=1}^I q_{iesr} \cdot Y_{iesr} \quad (15)$$

in livestock breeding:

$$G' \geq \sum_{j=1}^N q'_{js'r} \cdot X_{js'r} + \sum_{j=1}^N q'_{js'r} \cdot Y_{js'r} \quad (16)$$

e) fertilizers:

$$\begin{aligned} H_{hr} \geq & \sum_{k=1}^K q_{kesr} \cdot X_{kesr} + \sum_{i=1}^I q_{iesr} \cdot Y_{iesr} \\ & - \sum_{j=1}^N \hat{q}_{h js'r} \cdot X_{js'r} - \sum_{j=1}^N \hat{q}_{h js'r} \cdot Y_{js'r} \end{aligned} \quad (17)$$

Table 14. Fixed inputs.

Labor	Unit	Crop Labor			Livestock Labor	
		Permanent	Hirable	Seasonal	Permanent	Hirable
1. inventory level	man		a)			
2. average age	years					
3. retirement age	years					
4. working year	hours/years					
5. season 1 availability	hours/years			1		
6. season 2 availability	hours/years			1		
7. quality index permanent	index	1			1	
8. quality index hirable	index					
9. seasonal wage rate	\$/hour					
10. permanent wage rate	\$/year					
11. relative wage for hirable	% of permanent					
12. base run wage change over t=1,20						
13. base run hirable quantity change over t=1,20						

Notes:

a) - no data required

### Financial limitations

a) capital investments in plant growing:

$$C \geq \sum_{k=1}^K C_{kesr} \cdot X_{kesr} + \sum_{i=1}^I C_{iesr} \cdot Y_{iesr} \quad (18)$$

b) capital investments in livestock breeding:

$$C' \geq \sum_{j=1}^N C'_{jsr} \cdot X_{jsr} + \sum_{j=1}^N C_{jsr} \cdot Y_{jsr} \quad (19)$$

### Limitations in the conservation of nature

$$D_{er}^d \leq \sum_{k=1}^K \delta_{eksr}^d \cdot X_{eksr} + \sum_{i=1}^I \delta_{eisr}^d \cdot Y_{iesr} \quad (20)$$



### Equations of principle economic characteristics

$$P_g\{\geq\} \sum_{k=1}^K P_{sekr} \cdot X_{eksr} \sum_{i=1}^I P_{siesr} \cdot X_{iesr} + \sum_{j=1}^N P'_{jsr} \cdot X_{jsr} + \sum_{j=1}^N P'_{jsr} \cdot Y_{jsr} \quad (21)$$

### 3.7. Reverse Link Module

The reverse link module determines the recursive and dynamic nature of the model. Having analysed the decision vector of the major task of the linear programming model ( $t_i$  - period), the module develops correcting information for the ( $t_i + 1$ ) - period. The module is designed to use functions of temporary-trend type for the calculation of increments (both positive and negative) of labor resources, capital investments, and means of chemicalization.

### 3.8. Interface Modules

The introduction of the interface modules is connected with the fact that autonomous programming complexes (LSP/360, MPS/380) are assumed to be used to decide the tasks of the linear programming model; linear programming can be used in automatic management systems. The interface module, which is located before the decision block, effects the processing of the matrix of the coefficients into the job batch suitable for operation with a corresponding linear programming system. A module which is located after the decision block, effects the end printing and dumping of the information; the latter can also be transferred to the next module.

### 3.9. Optimization of the Structure of Motor Vehicles and Tractors

The choice of an optimum structure for the fleet of motor vehicles and tractors is made in an independent decision block for reasons given below.

1. As the structure of arable lands has been stabilized by the production process, the related volume of machine operations stabilizes as well.
2. The choice of an adequate power unit depends on its economic characteristics and the volume of work to be carried out in a given period.
3. The optimization model for structuring the fleet of motor vehicles and tractors has now been well developed and is used successfully both in the USSR and abroad. The models of R. Khabatov (USSR) and D. Hunt (USA) should be mentioned as being among the earliest developed.

Exclusion from the main linear programming model of problems related to the choice of means of mechanism results in a considerable reduction of matrix size, with a subsequent reduction in total input values (materials, finances, etc.).

4. Various technologies included in the model have different characteristics regarding energy input. However, the choice of an adequate technology is determined not so much by short-term economic profits and benefits, as by the ecological and long-term economic consequences of its application. This underlines the necessity of the independent decision block mentioned above.

The given task is assumed to have an individual calculation period (time limits), e.g. a 5-year calculation and generalization period. The mathematical model for the task will not be discussed here. In order to prepare the matrix, results of the decision for the main task, as well as normative and reference information, are used.

#### **4. Principle Operation Mode of the Model**

Whatever criterion of optimization is chosen, the final results depend to a considerable extent on a set climatic situation.

Assuming that the generation of the matrix involves no limitations to the choice of possible crop rotation schemes and technologies, during the course of the full-operation term of the model (20 years), we shall actually obtain images of optimum plans by years. Their relations are minimal. In favorable years conventional technologies, such as high fertilizer application rates, fallow-free crop rotation schemes, dry farming system, are more effective; in such years, the effect of the preceding crop is reduced to a minimum. However, the advantages of irrigation, soil conservation technologies, and special crop rotation schemes, will be felt beyond any doubt in years of unfavorable climate.

Keeping the above in mind, two stages of model operation are proposed:

The first stage- to obtain an initial decision for the task of the linear programming model; the result of the decision will be determined by the first-year climatic situation; the choice of the latter depends on the purpose of the experiment.

The second stage- to run the model to the full length of the generalization period with additional limitations to crop rotations, technologies, soil conservation, and erosion control measures.

At the first stage the chosen crop rotation schemes are not changed. Change is allowed only in cases where the the plot is transformed (e.g. the shifting of dry farming land to the irrigated land category), or in some other special cases.

Thus, after the first stage, the size of the matrix will be reduced considerably, owing to the exclusion of alternative crop rotation schemes.

As far as alternative technologies and soil conservation and erosion control measures are concerned, two equal approaches are possible:

- the exclusion of alternatives, and
- the one-way transition from a conventional technology to a soil conservation technology, from large rectangular fields to contour strip and strip cropping.

Using invariable crop rotation schemes does not mean that the tasks to be solved for a particular year will be excluded. In particular, problems related to the use of capital investment and livestock feeding rations are solved. At the second stage variations of variables related to livestock breeding branches are also limited.

The above approach is possible only when market and price policies are not of major importance, when the problem of specialization has been settled, and crop rotation schemes have been stabilized.

Irrespective of what optimization criterion was assumed at the initial stage of module operation, the global criterion problem needs to be settled so that the final results for the full period of the model run can be estimated.

It is not likely that a simple solution to this problem will be found, but initial versions can be compared using the following criteria:

-- maximum stability of gross output:

$$\min \sum (P_i - \bar{P})^2;$$

-- a steady growth of production:

$P_t < P_{t+1}$ , where "P" is a production level for a given period of time (e.g. 5 years);

-- an increase in soil fertility:

$$I_{t+1} - I_t > 0;$$

-- the prohibition of environmental pollution beyond a given level.

During the course of selecting input data, modeling, and the subsequent analysis of results, concrete questions related to problems of material resources, technology, scientific progress, and the environment should be answered.

Given below are the questions related to material resources:

1. What types of resources are now being used and will be used until the year 2000?
2. What resource limitations are encountered and which ones will be encountered by agriculture?
3. How can the use of power resources be improved?
4. What sources of power can be used in agriculture?
5. What will be the consequences of intensified agricultural development based on mechanization, extensive fertilizer and pesticide application, irrigation, and various forms of labor organization?
6. What negative effects, if any, can be expected as a result of the application of various methods of saline soil amelioration? expected?
7. The evaluation of the role of private farming, its requirements and estimated output should be carried out to a certain extent. We will consider the effect and possible consequences of various political decisions on the problem.

Since the term "technology" implies ways and means of putting production processes into practice, resulting in qualitative changes in objective, technology problems are closely related to problems of resource use and environmental effects. The following questions need to be answered:

1. What are the most acceptable technologies in plant growing, livestock breeding, feedstuff production, and primary processing in agriculture in the Stavropol territory now and in the future?

2. What are the principle elements of such technologies?
3. What resources will be required for the introduction of new technologies?
4. What are the possible effects of technological change on the environment?

Questions to be answered regarding the environment:

1. What are the most detrimental consequences of technological application and resource use in agriculture in Stavropol?
2. To what extent are negative environmental changes acceptable?
3. The estimation of the environmental effects of newly introduced technologies.
4. The measures to be taken to prevent extensive environmental changes.

When answering these questions, questions related to the possible social and economic consequences (such as, population migration, the requirements for skilled labor, the construction of social infrastructure units, etc.) also need to be considered.